Internet of Things 25 (2024) 101029

Contents lists available at ScienceDirect

Internet of Things

journal homepage: www.elsevier.com/locate/iot

Design and implementation of intelligent monitoring system for agricultural environment in IoT

Yongchao Song, Jiping Bi, Xuan Wang *

School of Computer and Control Engineering, Yantai University, Yantai, 264005, China

ARTICLE INFO

Keywords:
Smart agriculture
IoT
Cloud platform
Greenhouse control
STM32

ABSTRACT

In the context of population growth and limited resources, the efficiency and sustainability of agricultural production became particularly important. Smart agricultural technology and Internet of Things (IoT) technology have helped farmers with better management tools to improve crop yield and quality. This research takes the IoT as the core and combines sensor, actuator and cloud platform technologies to build a smart greenhouse control system. Environmental parameters such as temperature, humidity, and light are obtained through sensors. And it is uploaded to the cloud platform for storage and analysis. At the same time, light, ventilation, water, and fertilizer inside the greenhouse are controlled automatically by our system to achieve the best crop growth condition. System design adopts a modular design concept. We separately realize the functions of sensor, actuator and cloud platform, where data is transmitted via wireless communication and integrated together. The experimental results show that the cloud control system of smart agricultural greenhouse can effectively monitor the greenhouse environment, optimize efficiency of energy and resource utilization, and help farmers manage greenhouse conveniently and quickly.

1. Introduction

Smart agriculture is an agricultural development mode that uses modern science and technology to improve agricultural production efficiency and reduce resource waste. With the growth of the global population and the impact of climate change, traditional agriculture is facing many challenges such as land scarcity, water scarcity, and environmental pollution. Under this background, smart agriculture emerge as the times require. It achieves precise management and intelligent decision-making in agriculture through applying advanced sensing technology, cloud computing and IoT [1].

Greenhouse agriculture is one of the most important. Greenhouses provide controlled environmental conditions that allow plants to grow at any time of the day or night. At present, the application of IoT in agricultural greenhouse management has become a hotspot of human attention. It has changed traditional agriculture which is limited by many factors such as natural environment, geographical location, and climate. Smart greenhouse control system can realize the development and application of smart agriculture. It can monitor and control aspects such as light, water flow, inlet pipe pressure, supply voltage, ground temperature and humidity, air temperature and humidity, and so on, in order to improve the agricultural production efficiency of greenhouse [2]. However, there are still some problems in current greenhouse agriculture. Since environmental parameter in greenhouse is usually set by human, such as temperature, humidity, light and so on. Therefore it is unable to accurately monitor and manage the environment and crop growth. In addition, productivity is affected by seasonal and weather conditions that limit greenhouse crop growth [3].

* Corresponding author.
E-mail address: xuanwang91@ytu.edu.cn (X. Wang).

https://doi.org/10.1016/j.iot.2023.101029
Received 20 September 2023; Received in revised form 29 November 2023; Accepted 7 December 2023
Available online 13 December 2023
2542-6605/

Fig. 1. Smart agriculture greenhouse.

The Smart Agriculture Greenhouse Cloud Control System is designed to solve these problems in an IoT way, as shown in Fig. 1. Based on IoT technology, the sensor network can monitor environmental parameters and crop cultivation inside and outside greenhouse in real time. And it transmits these data to the cloud platform for processing. Cloud computing and big data analytics can generate appropriate control strategies on cloud platform based on crop needs and growth patterns. The cloud platform sends commands through control equipment, thus adjusting temperature, humidity, carbon dioxide and other environmental parameters in the greenhouse, eventually realizing precise control of crop growth environment [4]. In this way, crop yield can be maximized, resource use can be improved, energy consumption can be reduced, and stability in crop production and quality can be ensured. Therefore, it is an ideal solution to solve problems and difficulties of current greenhouse grow systems by creating a cloud-based smart greenhouse control system. It achieves precise monitor and control of the environment inside and outside greenhouse and the growth of crops through applying advanced information technology. And it improves resource utilization efficiency, optimizes production management, and improves crop yield and quality. Smart agricultural greenhouse cloud control system can bring high economic benefits to farmers, reduce environmental harm and promote sustainable development of agriculture [5].

This paper aims to design a smart agricultural greenhouse cloud control system based on IOT to achieve the above objectives. The system workflow is as follows. Firstly, environmental data be collected by STM32 microcontroller, wireless communication module, sensors and other devices. Then, ESP8266 WiFi module transmits the data to AliCloud's interface, and these data are visualized on the cloud. Finally, the user can connect to the cloud by cell phone or computer to view greenhouse environmental conditions in real time. Through the above research methodology and experimental design, we hope to derive the effect of smart agriculture greenhouse cloud control system to improve greenhouse agricultural production efficiency, save energy, change crops growth environment and other aspects. It provides a useful reference for the development of IoT and smart agriculture.

The remainder of the paper is organized as follows: Section 2 highlights related work that has been done and is in progress in the area of greenhouse control. Section 3 discusses the various components used in the proposed system. Section 4 describes the architecture and implementation of the system. Experimental results of the proposed work are given in Section 5. Section 6 discusses the conclusions and future scope.

2. Related work

Smart greenhouse control is a very interesting research topic and researchers have been working on smart control systems for agricultural greenhouses. This section gives a brief description of existing solutions for developing the smart control of greenhouses.

At present, designing and developing control systems by using IoT, has become a trend in the application of agricultural greenhouse management technology. It changes the situation of traditional agriculture, which is constrained by a variety of factors, including the natural environment, geography and climate. People have designed smart control system applications through IoT. It effectively improves environmental conditions inside greenhouse, which includes temperature, humidity, light intensity and carbon dioxide concentration, and other factors. So it has positive significance for improving crop yield and quality [6]. IoT agricultural greenhouse measurement and control technology can realize the automatic detection of agricultural area information. For example, we can set up wireless sensor nodes, information collection devices, information routing devices, solar power supply system and wireless sensor transmission system. In this way, we can monitor parameters such as soil moisture, soil temperature, air humidity, temperature, light intensity and plant nutrient content [7]. Where the wireless sensor aggregation nodes are created through IoT [8]. The system dynamically manages, displays, analyzes and processes the greenhouse's environmental factors and provides visualization graphs for the farmer. Depending on crop need, system provides information about various text, sound and light alarms. IoT greenhouse smart measurement and control system realizes automatic operation of the greenhouse. It not only reduces energy consumption and operating costs, but also provides an ideal growth environment for plants. In addition it reduces people's work intensity and improves equipment utilization. It also improves greenhouse climate, reduces pests and diseases, and increases crop yields [9].

Greenhouse farms still face many challenges in terms of efficient operation and management. Continuously evolving IoT technology, including smart sensor, device, network topology, big data analytic, and smart decision-making, is recognized as a solution to solve major challenges in greenhouse agriculture. For example, it is used in greenhouse local climate control, crop growth monitoring and crop reaping [10]. With agricultural informatization level constantly improving, Chinese greenhouse smart measurement and control system has made great progress in terms of technology and scale. However, we still have a big gap in the field of smart greenhouse control compared with developed countries, especially in production stability control, modernization and industrialization of supporting facilities [11]. Overseas greenhouses often use automatic control system to monitor and control greenhouse environments. These systems usually include sensor, actuator and controller. Sensor is used to monitor environmental parameters such as temperature, humidity and light. Controller sends commands to make devices such as ventilation and irrigation work to keep ideal environmental conditions in the greenhouse. Control methods use advanced control techniques, including fuzzy control, model predictive control, neural network control and adaptive control. Besides, it uses physical model-based control, state feedback control and control methods based on optimal control theory. They are all well known in improving greenhouse crop production performance, and these control technologies usually have strong data analysis and decision support capabilities. It collects and analyzes data about the greenhouse environment and plant growth. Based on the data, the system is able to provide accurate decision support and optimize management strategy [12].

In contrast, China's greenhouse control has just started, and most of greenhouses are manually operated. There are fewer control methods, only traditional PID control, fuzzy control, neural network control and so on. Greenhouse data analysis and decision support levels are relatively low, and there is still much improvement space [13]. However, Chinese greenhouse control systems can be better adapted to need and actual situation of local agriculture. Since local agricultural organization and crop characteristics are different from other countries, China's greenhouse control system is closer to the needs of domestic agriculture in terms of design and functionality. So it can provide more personalized and precise control strategies and technical solutions [14]. China is a vast country, farmers are relatively conservative in their thinking, and it is difficult to unify the standards of the agricultural industry chain. As a result, there are difficulties in collecting, analyzing, integrating and sharing information resources. In terms of agricultural production, small farmers are the majority. That is why it is difficult to unify scale, mechanization and systematization. The cultural level of farmers is generally low, so that the promotion of smart technologies and ecological concepts is not progressing fast enough. In addition smart agricultural technology development has three major contradictions and problems: resource environment, science and technology shortcomings, and institutional deficiencies [15].

In traditional greenhouse, climatic variables and other growth methods depend on the grower's assessment. But smart greenhouse growing is a closed growing process where greenhouse is managed through information and communication technology (ICT). It improves quality and quantity of crops and minimizes human participation [16]. Emerging IoT technology offers huge potential to develop innovative approaches and smart solutions that can change the agriculture sector in every way. Therefore, combining IoT with greenhouse and transforming them into smart automatic greenhouse is considered as one of the most ideal solutions [17].

When the IoT started to emerge, some people started to research smart greenhouse. Li et al. [18] have proposed an agricultural greenhouse environment monitoring system based on IOT, combining the Internet, wireless networks, and mobile. It realizes remote real-time monitoring of greenhouse environmental information. The implementation method is as follows. Through ZigBee protocol, a wireless sensor network was built for collecting environmental information such as temperature and humidity. Finally, the collected environmental information was accessed to the Internet and mobile network through the control center, which realized the SMS heating and real-time monitoring of agricultural environmental information. However, when a text message is received, it cannot be immediately controlled accordingly. Such as when the temperature is too high, the vent opening size cannot be regulated immediately. Ahmad et al. [19] have proposed a method for greenhouse management and monitoring using Memsic and Zigbee technology. The system can monitor soil temperature and humidity, air temperature, and light radiation. All sensors are able to collect data from the greenhouse and send it to the microcontroller on a regular basis. Data is sent from transmitter to the

Table 1
NMEA-0183 common command table.

No	Command	Description	Maximum frame length
1	$GPGGA	GPS location information	72
2	$GPGSA	Current satellite information	65
3	$GPGSV	Visible satellite information	210
4	$GPRMC	Recommended positioning information	70
5	$GPVTG	Ground speed information	34
6	$GPGLL	Geodetic coordinate information	–
7	$GPZDA	Current time (UTC1) informationr	–

receiver and displayed on a device such as smartphone, laptop or PDA. It uses MP Lab and LabView softwares in programming and interfacing process. Although the system can monitor the growing environment of the greenhouse through the device, it cannot control greenhouse remotely.

With the development of IoT, more and more programs are proposed. Cao et al. [20] proposed a wireless agricultural monitoring platform by Mesh Wi-Fi network. The system consists of a root node, three relays and six nodes. Each node has three sensors for measuring parameters, including soil moisture and soil temperature, ambient temperature and ambient humidity of the farm, and light intensity. The collected data is transferred from the node to the root node, then updated to the cloud database and displayed on the dashboard. The MEAN stack-based site will create real-time information tracking and keep historical data for the owner. However, the system does not have a complete cloud-based platform, so it cannot remotely control greenhouse operations by Internet.

The system built through wireless sensor networks and cloud platforms works extremely well. Ping et al. [21] have proposed an IoT and ARM-based framework for soil moisture control and irrigation management. In this system, the values obtained by the sensors are stored on a cloud server and necessary suggestions are provided over the web. When the ground temperature is high and soil moisture is low, an automatic irrigation system is triggered and the user is also notified by email. Users can easily monitor the irrigation system through the cloud server and mobile web application. Jing et al. [22] have proposed a distributed agricultural service system that integrates social and physical information in order to provide decision support from farmers. The system uses wireless sensor networks, cloud computing, and distributed systems architecture to manage people, plots, crops, and equipment. Services include crop planning, production guidance, and equipment control. User terminals include computers, mobile applications and applets.

3. Components used in the proposed system

The composition of a control system needs to have controller, sensor, actuator, controlled object. In addition, it also needs communication module, display module and so on. They work together to form a perfect control system.

The proposed system provides a cost-effective solution for detecting environmental conditions in greenhouses, which can be controlled automatically or manually remotely through the Internet.

According to the current price, accuracy, and ease of use of controllers and sensors; the applicability and difficulty of compiling software; and the price and applicability of cloud platforms, we choose following components. But users can choose higher accuracy sensors or faster speed controllers depending on the specific use situation, which of course means a higher price.

3.1. STM32F407ZGT6 microcontroller

The STM32F407ZGT6 is a microcontroller unit based on a high-performance ARM Cortex-M4 32-bit RISC core operating at up to 168MHz. Cortex-M4 core has a floating point unit (FPU) single precision and supports all ARM single-precision data-processing instructions and data types [23]. It also implements a full set of DSP instructions and a memory protection unit (MPU) for enhanced application security. It offers three 12-bit ADCs, two DACs, a low-power RTC, twelve general-purpose 16-bit timers, including two PWM timers for motor control, and two general-purpose 32-bit timers.

3.2. Beidou/GPS module ATK-1218-BD

The ATK-S1216F8-BD is a high-performance GPS/BeiDou dual-mode positioning module [24]. The microcontroller can communicate with the module through the serial port to get information, which include latitude, longitude, altitude, speed, positioning mode, number of satellites used for positioning, number of visible satellites, and UTC date and time of the module's location. The RTCM standardized protocol for GPS navigation devices is described in Table 1.

3.3. Wind cup wind speed sensor

The sensing part of the wind speed sensor is formed by three conical or hemispherical empty cups [25]. Three hemispherical or conical hollow cup shells are fixed to a trident star-shaped bracket at 120° to each other or to a cross-shaped bracket at 90° to each other. The bracket made of plastic or alloy. The inductive part is connected to an engine. The empty cup rotates, driving the engine rotor to produce current. When the rotor is faster, the current is higher and the voltage at the ends of the generator is higher. The wind speed sensor is connected to the microcontroller through a connecting wire, which is used to measure the voltage across the sensor and then obtain the actual wind speed. Based on the wind speed, the wind level at that time is obtained through a self-writing program. The wind speed sensor output voltage signal and wind speed calculation formula is shown in Eq. (1):

$$F = 0.027 \times V, \tag{1}$$

where F means wind speed in m/s, V means voltage in mv.

3.4. Raindrop sensor

The sensor is made of high-quality FR-04 double-sided material with a large area of 5.0×4.0 cm, and its surface is treated with nickel-plating technology [26]. Therefore, the module has excellent performance in terms of oxidation resistance, electrical conductivity, and longevity. In addition, the module is capable of data transfer via digital and analog.

3.5. DHT11 temperature and humidity sensor

The DHT11 is an integrated temperature and humidity sensor that includes a moisture-measuring element and a temperature-measuring element [27]. The communication method between the DHT11 and the microcontroller is single bus communication, so that only one data line is required to achieve communication with the microcontroller. In addition, the DHT11 has very low power consumption. When the operating voltage is 5 V, the average maximum current is 0.5 mA.

3.6. BH1750FVI digital illuminance sensor

The BH1750FVI digital illuminance sensor module is a digital integrated circuit for serial bus interface. It uses the IIC communication protocol, operates on DC5V, and its input illumination range is from 1 to 65 535 lx [28].

3.7. SGP30 gas sensor

The SGP30 is a gas sensor that provides detailed information on actual air quality level or concentration, such as ppm for airborne CO_2 and actual level of volatile organic compound [29]. The module has excellent long-term stability, resistance to contamination caused by silicone, TVOC output, and H2-based CO_2 equivalent output.

3.8. Wireless communication module NRF24L01

The NRF24L01 is a wireless communication module with FSK modulation and NORDIC Enhanced Short Burst Protocol. It supports point-to-point or point-to-multipoint wireless communication up to six nodes. The communication band is 2.4G, and the communication rate is up to 2 Mbps. The module adopts the highly efficient GFSK modulation method, which has strong anti-interference ability. It can realize the requirements of multipoint or specific frequency modulation communication in 126 selectable channels. The features and benefits of the module are summed up below:

- **Long wireless communication range.** The NRF24L01 module supports the 2.4 GHz ISM band. It has adjustable communication range that can reach about 100 m in the best case.
- **Reliable and stable.** NRF24L01 module adopts frequency hopping technology. It has strong anti-interference and stability performance. It can keep excellent communication quality in complex wireless environment.
- **Fast response time.** The NRF24L01 module has fast switching times and transmission rates up to 2 Mbps. Thus, it is well adapted for real-time data transmission and applications that requires fast response times.
- **Multinode communication.** The NRF24L01 module supports multinode network communication. It can achieve communication modes of point-to-point, point-to-multipoint and multipoint-to-multipoint. As a result, it can flexibly adapt to the needs of various communication topologies.
- **Simple interface.** NRF24L01 module connects to the microcontroller with simple interface that uses SPI communication protocol. Therefore small number of I/O pins can realize communication with external controller.
- **Cost-effective.** The NRF24L01 module offers excellent performance and price ratio. It is one of the cost-effective wireless communication solutions for many IoT and embedded applications.

Although 2.4 GHz frequency wireless communication has high penetration power, the communication distance is relatively short. In practical applications, when communication distance exceeds 100 m, it may encounter problem that data cannot be reliably received. For longer communication distances, LORA communication module with 433 MHz frequency can be considered as an alternative to NRF24L01. LORA technology has a larger communication range that can reach several kilometers or even farther. However, it is important to note that as an alternative, LORA communication module can be more expensive, it costs three times as much as NRF24L01.

3.9. ATK-ESP8266 WiFi module

The ATK-ESP8266 is a high-performance UART-WiFi module [30]. The communication modes are as follows. ATK-ESP8266 module communicates data with a microcontroller through serial port communication and can realize transformation between serial port and WiFi. After configuring the serial port, this module can transmit data through the network. For example, when the module is configured with relevant parameters through AT commands, it can connect to WiFi. After that it can connect to the cloud based on domain name, protocol of the cloud platform.

In addition the selected ESP8266 module can be replaced by 4G DTU in case of higher requirements. But the price is several times of ESP8266.

3.10. TFTLCD screen

TFTLCD, also called Thin-Film Transistor Liquid-Crystal Display, is a flat panel display made using thin-film transistor technology and liquid crystal display technology. It consists of thin-film transistor array, liquid crystal material layer, color filter layer and backlight. The liquid crystal display (LCD) has a thin-film transistor (TFT) set on each pixel. Which can effectively avoid crosstalk during non-selective, and make the static characteristics of LCD independent of the number of scanning lines. Thus the image quality is greatly improved. TFTLCD has the following characteristics: high resolution, good color performance, wide viewing angle, fast response time, low power consumption. We chose the size of 7-inch screen, which resolution is 800 × 480, with 16-bit true color display.

3.11. Keil5 development software

Keil5 is an embedded system development tool. It provides a complete programming environment. It includes code editor, debugger, compiler, emulator and downloader. In addition, it supports many different microcontroller architectures such as ARM, Cortex-M and 8051. All in all, Keil5 is a powerful, easy to use embedded software development tool that helps developers quickly build high quality embedded systems.

3.12. AliCloud IoT platform

AliCloud IoT platform is an Internet-based IoT solution provided by AliCloud. It provides a series of technologies and tools, and it supports the access, management and data interaction of IoT devices. It is widely used in the field of IoT and can support IoT applications in a variety of fields such as smart home, smart industry, and smart transportation. Users can realize a variety of business needs, such as device interconnection, data sharing, intelligent analysis, and so on, through the AliCloud IoT platform. Which effectively improves the intelligence and sustainability of IoT applications.

4. Architecture and implementation

The architecture of the proposed system is shown in Fig. 2. It consists of four parts: sensor acquisition control network, network transmitter, application platform, and greenhouse equipment management.

Sensor acquisition control network collects the environmental information in real time; BeiDou/GPS module performs the location positioning; TFTLCD screen displays the collected data, latitude, longitude, time and other information in real time [31]. The wireless communication module is responsible for information interaction with the network transmitter [32]. Network Transmitter's role is sending the environmental information collected by the received sensors to the cloud through the ESP8266WiFi module. These information processed and stored in the database. Sensor acquisition control network and network transmitter systems use hardware as shown in Table 2. The application platform is built on AliCloud IoT platform [33]. After building the project and connecting the devices, we create various physical models and display the data on the cloud platform. Through data communication and information interaction, visualization platform is constructed on the AliCloud platform. It includes a Web-side visualization platform and a mobile-side visualization platform. We can access the Internet through a computer or cell phone, thus enabling automatic control the various agricultural equipment in the greenhouse.

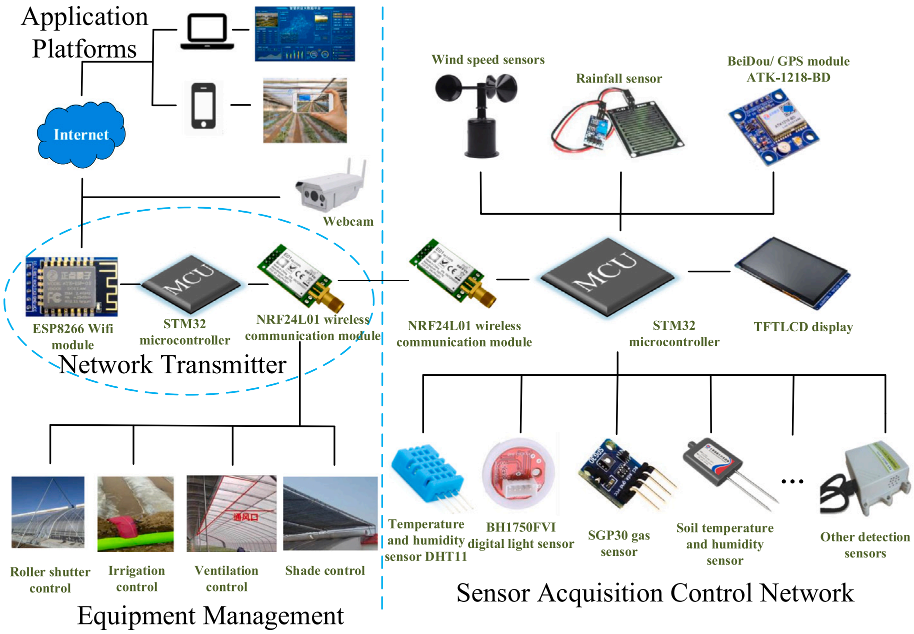

Fig. 2. Overall structural design of the system. Right: Sensor Acquisition Control Network, which collects information about various environments. Bottom left: Equipment Management, which represents the agricultural equipment in the greenhouse. Middle left: Network Transmitter, which receives information from the greenhouse and sends it to the cloud platform. Upper left: Application Platform, which detects and controls the greenhouse system.

Table 2
Hardware required for sensor acquisition network and network transmission.

Equipment	Number	Function
STM32F407ZGT6	1	The device is the controller as the core of the entire sensor network
TFTLCD	1	Display of collected data and other information
Beidou/GPS Module ATK-1218-BD	1	For positional localization
Wind cup wind speed sensor	1	Measuring phoenix speed
Raindrop sensor	1	For sensing rain
DHT11 temperature and humidity sensor	2	Detecting temperature and humidity inside and outside the house
BH1750FVI digital illuminance sensor	1	Detecting light intensity in the greenhouse
SGP30 gas sensor	1	Detecting carbon dioxide concentration in the greenhouse
DS18B20 temperature sensor	1	Detecting soil temperature
Soil moisture sensor	1	Detecting soil humidity
Wireless communication module NRF24L01	1	Wireless communication for the system
STM32F103RCT6	1	The device is a controller that serves as the core of the network transmitter
ATK-ESP8266 WiFi module	1	Connects to the network and uploads data
OLED screen	1	Displays the status of the network transmitter

Sensor acquisition control network. The STM32F407ZGT6 is used as the main controller to obtain the air temperature and air humidity inside and outside the greenhouse through the DHT11 temperature and humidity sensor, get the light intensity inside the greenhouse through the BH1750FVI digital illuminance sensor, get the carbon dioxide concentration inside the greenhouse through the SGP30 gas sensor, get the temperature and humidity of the soil in the greenhouse through the soil temperature and humidity sensor, get the wind speed outside the greenhouse through the wind speed sensor, and get the rainfall outside the greenhouse through the rainfall sensor [34]. At the same time combined with BeiDou/GPS module for location positioning. The information obtained after comprehensive processing is displayed on TFTLCD liquid crystal display [35]. Through the NRF24L01 wireless communication module, the collected data are sent to the network transmitter according to the specified communication mode, communication address, and communication band [36].

Network transmitter. The network transmitter uses the STM32F103RCT6 microcontroller as the main controller. In the environment with network, the ESP8266 module can automatically connect to the network and AliCloud platform after the microcontroller is power on. The wireless communication module receives the data which is sent from the sensor acquisition and control network, and then it is sent to AliCloud through the ESP8266 module. The working condition is displayed on the OLED screen.

Application platform. First of all, we need to write C program by keil5 software. That is, according to the information of ESP8266, we write AT command suitable for UART serial port. Then, microcontroller makes use of the serial port to communicate with ESP8266 module. The purpose is make the ESP8266 module connect to Aliyun by successively receiving a reset command, a mode setting

Table 3
Hardware required for vent consoles.

Equipment	Number	Function
STM32F407VET6	1	The device is a controller as the core of the vent control terminal
Stepper motor	1	Controls the size adjustment of the vent
Threaded screw	1	Mechanism of the vent
Switching power supply	1	Power supply to the motor
ATK-ESP8266 WiFi module	1	Connects to the network and uploads data
OLED screen	1	Displays the status of the network transmitter

command, a WiFi connection command, and a connect to Aliyun domain name command. After that, microcontroller sends topic subscription through MQTT protocol. ESP8266 connects through the Internet and sends relevant data according to MQTT protocol. AliCloud performs JSON data parse to communicate between ESP8266 and cloud. AliCloud distributes the data through data transfer protocol so that server gets a series of data streams. As a result, internal servers such as Web server are able to perform display and control operations based on the constructed visualization platform. Finally, we inserted component models on the visualization platform to connect physical devices and uploaded data.

Network data big screen control is usually used in larger scale data monitor and display scene. For complex data management and control need, big screen control can provide better operation experience and detail display. In contrast, the mobile control is less, screen size is limited, display of information and charts is relatively small. The big data screen in cloud control is usually fixed operation site. While mobile control has greater flexibility and portability. Users can monitor and control through mobile phones anywhere and anytime. According to specific use scenario and need, users can choose the control method that suits them.

Greenhouse equipment management. First of all, the various agricultural equipment in the greenhouse needs to be networked with wireless devices in the 2.4G band, so that it can communicate with the network transmitter. TThen, the device can turn on or off by receiving data commands. For example, opening and closing of irrigation valves, size of valve openings, and extent of irrigation in a greenhouse are determined by soil moisture sensor, water level sensor, and webcam. For roller shutter control, the system has three phase motor switching control, insulation blanket position detection, data uploading, and so on. In the control of the sunshade, the system has shade and retraction control of the sunshade and so on. However, the above operation is difficult to construct a hardware system, so we constructed a ventilation control device. The size of vent is controlled by a stepper motor [37]. The stepper motor is powered by a switching power supply with specifications of 220 V input and 24 V output. The ventilation system performs motion control combining information received from the sensors and position data measured by the laser distance measuring module. In addition, ESP8266 WiFi module can receive information from the cloud, which enables remote manual network control. The exact control information and relevant data are displayed on the OLED screen. The control algorithm employs dual-mode control, that is, PID control and Bang-Bang control. The Bang-Bang + PID control algorithm has high dynamic performance and can reduce response time and steady-state error of system [38]. Meanwhile, the algorithm is simple to implement and suitable for real-time control system.

The main controller is STM32F407VET6, which can receive sensor or Aliyun information through NRF24L01 module or ATK-ESP8266 WiFi module. Based on the received information, the program combines the environmental parameters to calculate the adjustment data for the vents. This value is used as controller output [39]. This value is converted to the frequency of the PWM output. Finally, the signal from the controller is output to the stepper motor controller so that the stepper motor can be controlled. The hardware used for the vent control system is shown in Table 3. The Bang-Bang + PID control algorithm is divided into two stages: When the system error is large, Bang-Bang control is used; when the system error is small, PID control is used. As shown in Eq. (2).

$$u_{(k)} = g_{(k)} K_P \left\{ e_{(k)} + \frac{T}{T_I} \sum_{j=0}^{k} e_{(j)} + \frac{T_D}{T} \left[e_{(k)} - e_{(k-1)} \right] \right\} + f_{(k)} K_B, \tag{2}$$

where $u_{(k)}$-control output; $e_{(k)}$-error between input and feedback; K_P-proportional coefficient; T-sampling time; T_I-integral time constant; T_D-differential time constant; K_B -output of Bang-Bang control. $g_{(t)}$ is the switching function of the two algorithms. When $g_{(t)} = 0$, $f_{(t)} = 1$, system is used for Bang − Bang control; When $g_{(t)} = 1$, $f_{(t)} = 0$, system is used for control.

5. Experimental results

We completed the system construct and debug in a laboratory environment. In addition, we tested certain outdoor environmental factors in a natural outdoor environment. The working model of the proposed system is shown in Fig. 3. The experiment consisted of the following stages.

5.1. Collection and transmission of environmental data

STM32F407ZGT6 collects data from DHT11 temperature and humidity sensors and DS18B20 temperature sensor by single-bus communication protocol; collects data from light sensor and SGP30 sensor by IIC communication protocol; collects data from wind

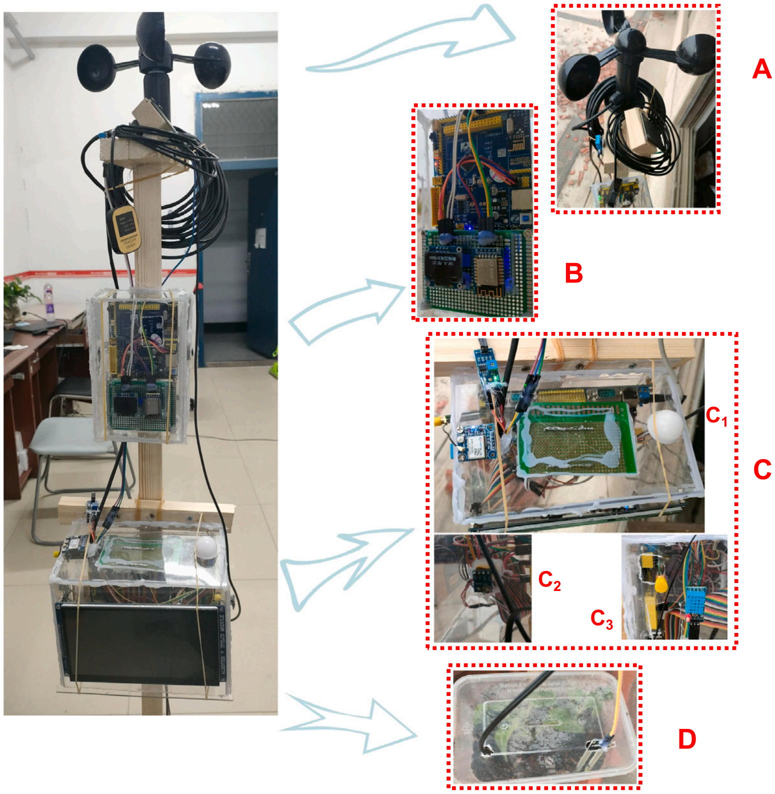

Fig. 3. Hardware of the system. The left side of the picture shows system hardware and the right side shows specific details. Part B is the network transmitter, which contains STM32F103RCT6, ESP8266, and OLED. Parts A, C, and D form sensor acquisition control network. Part A contains wind cup wind speed sensor, DHT11, raindrop sensor, and satellite position module antenna. Part C is the core part of the information acquisition, which is designed as a 'box'. Inside the "box" is STM32F407ZGT6 and in front is TFTLCD. Part C_1 is the upper part of the "box", equipped with ATK-1218-BD, BH1750FVI. Part C_2 is the right side of the "box", equipped with SGP30. Part C_3 is the left side of the "box", equipped with NRF24L01, DHT11. Part D is the soil measurement device (not shown on the left), which contains DS18B20 and soil moisture sensor.

speed sensor, raindrop sensor and soil humidity sensor by ADC interface, and receives positional information from BeiDou/GPS module by serial communication protocol.

Then, all of the above data are processed and displayed on the TFTLCD screen. According to the SPI communication protocol, the data are sent to the network transmitter by NRF24L01 wireless communication module.

When testing is performed, the designed device is placed in a simulated environment. During testing, we found that the microcontroller module is able to work as expected. The system can detect the environmental data and display it in the TFTLCD screen. The Fig. 4 shows the detected environmental data of the system in the simulated environment.

5.2. Network transmitter

The STM32F103RCT6 of the network transmitter receives the information through the NRF24L01 and sends it to the cloud through the ESP8266 module by MQTT transport protocol. And then the data will be stored in the server database. The data that it sends to cloud platform is shown in Fig. 5.

5.3. Device control

When the system controls equipment, the stepper motor can accurately perform the command. Laser ranging module can measure the vent accurately. The system control with high precision. Fig. 6 shows the working model of the ventilation device. The system receives the information collected by the sensors through NRF24L01 or the information sent from the cloud through ESP8266. Then, it realizes the exact control of the vent through the dual-mode control algorithm. At the same time, the network condition and the effect of information flow transmission are displayed in the OLED screen. It is cloud data is shown in Fig. 5. At this time, the system is in automatic control state. The control program is automatically adjusted according to the environmental parameters, and the manually set values are not involved in the control.

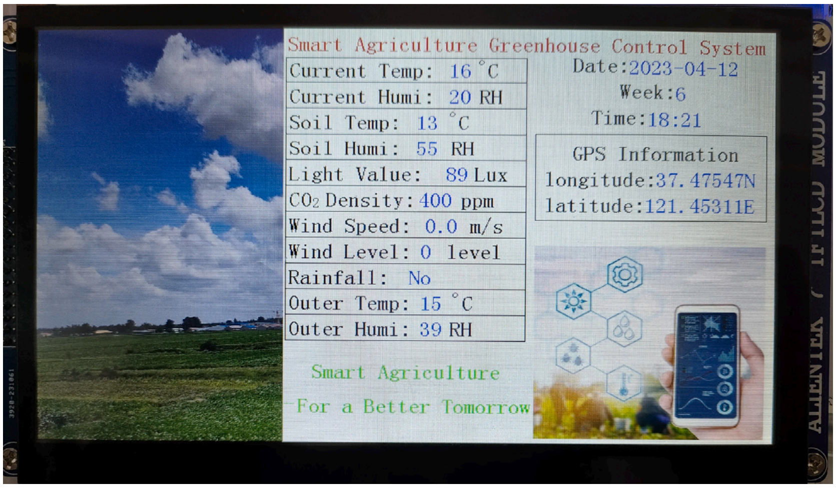

Fig. 4. Gathering environmental information in a simulated test environment.

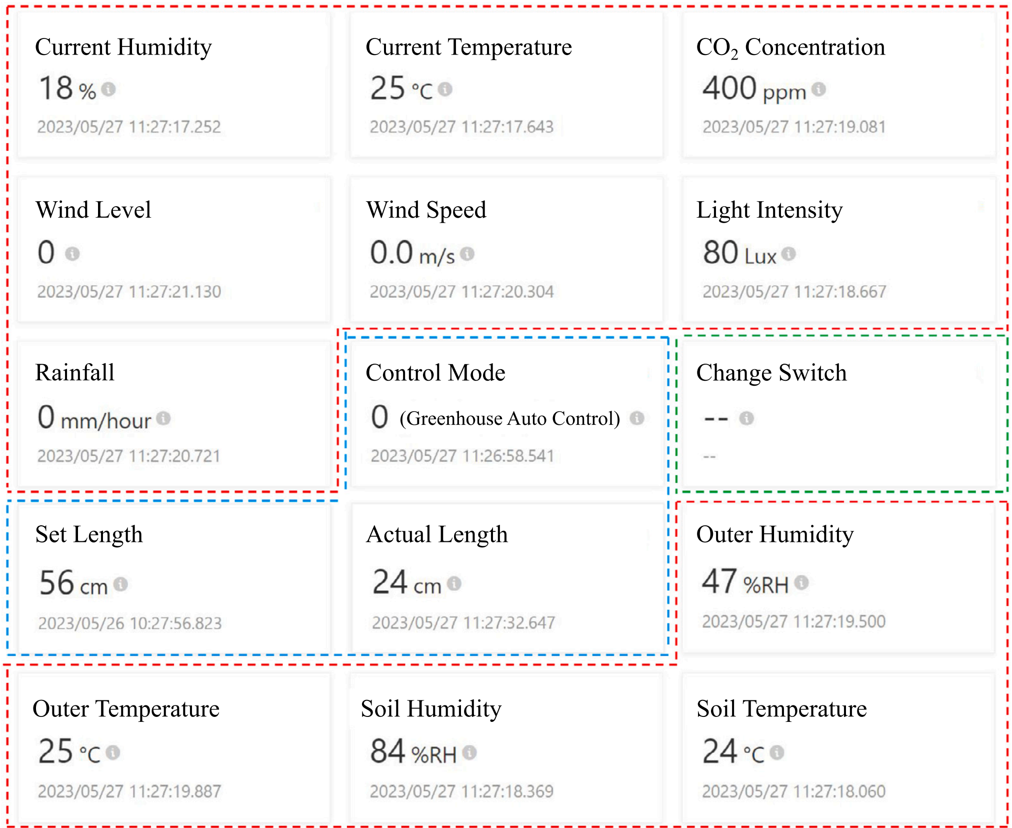

Fig. 5. Cloud data. Red box: Data collected by the sensor for uploading. Blue box: Data reported by ventilation devices. Green box: Transition data in cloud platform. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

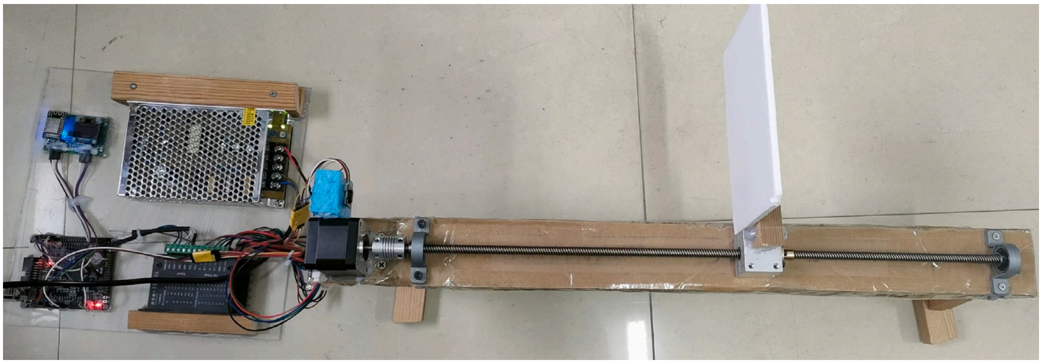

Fig. 6. Ventilation control. Laser ranging module is placed in front of blue square. The distance between it and the white board simulates the size of the vent. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 7. Web visualization large screen.

5.4. Cloud environment achieve

Various data stored in Fig. 5 database are visualized in the cloud and can control system operation.

Cloud data is used to build physical model and control operation accordingly. We achieved respectively data visualization on web and mobile device, as shown in Figs. 7 and 8. Through these experiments and tests, we have gained initial success and shown the system's potential for greenhouse automation control.

Cloud big screen. Cloud big screen is an integrative management system that combines multiple functions. It monitors and collects data in real time by connecting with greenhouse equipment and sensors, and transmits the data to the cloud to process and analysis. On the cloud screen, users can view various data in the greenhouse, such as temperature, humidity, carbon dioxide concentration and light level. In addition, the cloud screen also has a remote control function. Users can remotely operate greenhouse equipment, such as adjusting temperature, humidity and other parameters, which realizes exact control of the greenhouse environment. Users can access and operate the cloud big screen through computer or other terminal device, so as to easily monitor and manage the greenhouse in real time.

The cloud big screen provides farmers with convenient data monitoring, analysis, and control functions. It helps them to achieve smart agricultural management and improve crop production efficiency and quality.

Mobile cloud. Mobile cloud and cloud big screen, they can both transfer and share data through cloud service. Users can share data on different devices. They can realize the function is basically the same.

In complex control, the mobile device is no match for the network big screen control. However, for some simple functions, their realization is basically same. Mobile device control have some advantages compared to web big screen control. The mobile device is light and portable. It can be carried anywhere. Data can be displayed on mobile devices. Users can view the data anytime, anywhere which is not depend on a specific big screen device. As a result, it can meet the needs of users to analyze and make decision environmental data at any time.

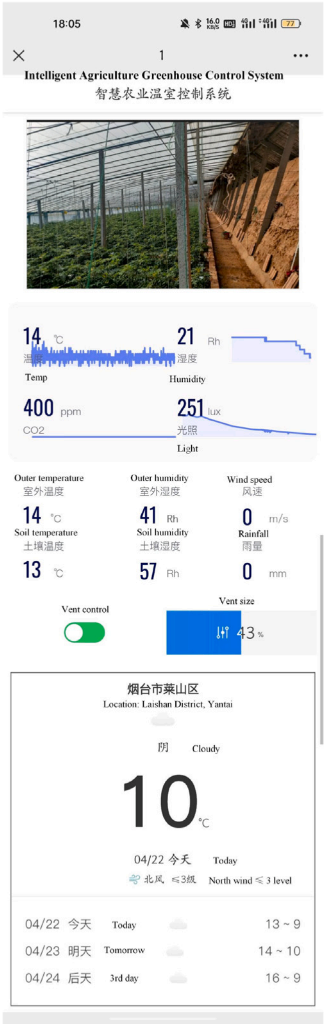

Fig. 8. Mobile cloud visualization.

6. Conclusions and future research work

6.1. Conclusions

The model put out in this work aims to accomplish centralized management and automated control, both of which are significant goals. A centralized monitoring and control center is provided by this technology, which centralizes the collection of greenhouse data in real-time. Through the cloud platform, administrators may check on changes to the greenhouse environment, crop growth, and numerous parameter indicators whenever and wherever they want. The cloud platform offers remote monitoring and management of greenhouse machinery, including irrigation systems, temperature control, and ventilation. To achieve automatic modification of the greenhouse environment and enhance crop quality and production effectiveness, administrators can remotely set control parameters through the cloud platform.

6.2. Future research work

However, despite the fact that the cloud platform can be automatically controlled by gathering data about the greenhouse's temperature, humidity, light, etc., there is no combination of data analysis and algorithmic modeling in the cloud platform to provide correct cloud control. That is one way forward. The given information can be used to further improve the system and expand its usefulness on the cloud platform. In order to create more accurate models and offer more precise management solutions, the greenhouse data obtained is thoroughly examined and learned from. For example, combining crop growth models and meteorological data to predict future trends in the greenhouse environment. From there, factors like ventilation and irrigation are changed to improve crop quality and yield. Following this, the settings for irrigation and ventilation are fine-tuned in order to optimize both crop quality and productivity.

CRediT authorship contribution statement

Yongchao Song: Formal analysis, Funding acquisition, Supervision, Writing – review & editing. **Jiping Bi:** Software, Visualization, Writing – original draft. **Xuan Wang:** Conceptualization, Formal analysis, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Xuan Wang reports financial support was provided by Natural Science Foundation of Shandong Province.

Data availability

No data was used for the research described in the article.

Acknowledgments

This research was funded by the Natural Science Foundation of Shandong Province, China (ZR2022QF037).

References

[1] A.U. Rehman, Smart agriculture: An approach towards better agriculture management, Omics Group. ebooks (2015).
[2] R. Zhao, Y. Ding, S. Ma, M. Wang, Design of intelligent greenhouse control system based on internet of things, in: 2019 2nd International Conference on Information Systems and Computer Aided Education (ICISCAE), IEEE, 2019, pp. 117–121.
[3] Y. Achour, A. Ouammi, D. Zejli, Technological progresses in modern sustainable greenhouses cultivation as the path towards precision agriculture, Renew. Sustain. Energy Rev. 147 (2021) 111251.
[4] S.D. Nath, M.S. Hossain, I.A. Chowdhury, S. Tasneem, M. Hasan, R. Chakma, et al., Design and implementation of an IoT based greenhouse monitoring and controlling system, J. Comput. Sci. Technol. Stud. 3 (1) (2021) 01–06.
[5] C. Maraveas, D. Loukatos, T. Bartzanas, K.G. Arvanitis, J.F. Uijterwaal, Smart and solar greenhouse covers: Recent developments and future perspectives, Front. Energy Res. 9 (2021) 783587.
[6] C. Li, Design and Implementation of Remote Monitoring System for Intelligent Agricultural Greenhouse Environment, (Master's thesis), Chongqing University of Posts and Telecommunications, 2021.
[7] A.D. Boursianis, M.S. Papadopoulou, P. Diamantoulakis, A. Liopa-Tsakalidi, P. Barouchas, G. Salahas, G. Karagiannidis, S. Wan, S.K. Goudos, Internet of things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: A comprehensive review, Internet Things 18 (2022) 100187.
[8] E.M. Ouafiq, R. Saadane, A. Chehri, Data management and integration of low power consumption embedded devices IoT for transforming smart agriculture into actionable knowledge, Agriculture 12 (3) (2022) 329.
[9] Z. Zhang, Research on intelligent measurement and control system for internet of things in greenhouse, in: Journal of Physics: Conference Series, Vol. 1486, IOP Publishing, 2020, 022037.
[10] R. Rayhana, G. Xiao, Z. Liu, Internet of things empowered smart greenhouse farming, IEEE J. Radio Freq. Identif. 4 (3) (2020) 195–211.
[11] H. Ranjun, C. Xianzhu, Implications of foreign smart agriculture development for rural revitalization in China, Contemp. Agric. Mach. (61-62+64) (2022).
[12] D.A. Gzar, A.M. Mahmood, M.K.A. Al-Adilee, Recent trends of smart agricultural systems based on internet of things technology: A survey, Comput. Electr. Eng. 104 (2022) 108453.
[13] H. Shanshan, Z. Jiezhong, Y. Zaiqiang, M. Yufei, Research progress on greenhouse environmental control in China, Chin. Agric. Bull. 37 (125–131) (2021).
[14] Y. Juan, L. Yuling, Z. Yuan, C. Yajing, An overview of the status quo and development prospect of smart greenhouse construction, South. Agric. Mach. 53 (36–44) (2022).
[15] Z. Yongxia, Research on modern agricultural development under the rural revitalization strategy, Rural Econ. Sci. Technol. 32 (286–288) (2021).
[16] C. Yaopeng, L. Houcheng, Application of big data and agricultural internet of things technologies in smart greenhouse environment control - A case study of jinan kobai intelligent agricultural industrial park, Agric. Eng. Technol. 41 (21–26) (2021).
[17] M.S. Farooq, S. Riaz, M.A. Helou, F.S. Khan, A. Abid, A. Alvi, Internet of things in greenhouse agriculture: A survey on enabling technologies, applications, and protocols, IEEE Access 10 (2022) 53374–53397.
[18] S.L. Li, Y. Han, G. Li, M. Zhang, L. Zhang, Q. Ma, Design and implementation of agricultral greenhouse environmental monitoring system based on internet of things, Appl. Mech. Mater. 121 (2012) 2624–2629.
[19] A.A.A. Halim, N.M. Hassan, A. Zakaria, L.M. Kamarudin, A.H.A. Bakar, Internet of Things Technology for Greenhouse Monitoring and Management System Based on Wireless Sensor Network (Ph.D. thesis), School of Computer and Communication Engineering, Universiti Malaysia Perlis, 2017.
[20] T.C. Pham, H.B. Vo, N.Q. Tran, A design of greenhouse monitoring system based on low-cost mesh wi-fi wireless sensor network, in: 2021 IEEE International IOT, Electronics and Mechatronics Conference (IEMTRONICS), IEEE, 2021, pp. 1–6.
[21] P. Tan, E.T. Gebremariam, M.S. Rahman, H. Salman, H. Xu, Design and implementation of soil moisture monitoring and irrigation system based on arm and iot, Procedia Comput. Sci. 208 (2022) 486–493.
[22] J. Hua, H. Wang, M. Kang, X. Wang, S. Guo, F. Chang, F.-Y. Wang, The design and implementation of a distributed agricultural service system for smallholder farmers in China, Int. J. Agric. Sustain. 21 (1) (2023) 2221108.
[23] Z. Jianbao, B. Shiping, L. Bing, Design of intelligent cooking machine based on stm32f407zgt6, in: 2022 2nd International Conference on Electrical Engineering and Control Science (IC2ECS), IEEE, 2022, pp. 1161–1166.
[24] W. Yifan, Research on Land Area Mapping Technology and Land Information System Based on Beidou/GPS Dual-mode Positioning, (Master's thesis), Ningxia University, 2023.
[25] W. Le, Principle of wind direction and wind speed sensor and its detection research, China Equip. Eng. (166–168) (2022).
[26] Z. Qiaoni, Comparison and study of raindrop sensor detection principles, Value Eng. 35 (253–254) (2016).
[27] F.M. Sharmila, P. Suryaganesh, M. Abishek, U. Benny, IoT based smart window using sensor dht11, in: 2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS), IEEE, 2019, pp. 782–784.

[28] Y.E. Windarto, D. Eridani, Door and light control prototype using intel galileo based internet of things:(case study: Embedded and robotics laboratory, department of computer engineering, diponegoro university), in: 2017 4th International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE), IEEE, 2017, pp. 176–180.

[29] J. Jose, T. Sasipraba, Indoor air quality monitors using IOT sensors and LPWAN, in: 2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI), IEEE, 2019, pp. 633–637.

[30] R.K. Kodali, S. Soratkal, MQTT based home automation system using ESP8266, in: 2016 IEEE Region 10 Humanitarian Technology Conference (R10-HTC), IEEE, 2016, pp. 1–5.

[31] Y. Zhijia, C. Xiaoping, Research on TFTLCD display driver scheme for STM32F429, Microcontroller Embed. Syst. Appl. 16 (44–47) (2016).

[32] Y. YinKun, C. LiQiong, Wireless temperature and humidity harvesting and alarm system design based on nRF24L01, Wirel. Connect. Technol. 19 (63–64) (2022).

[33] K. Liu, S. Wang, W. Cheng, W. Yang, S. Yang, Research on middle platform construction and large data analysis of power enterprises based on aliyun, in: 2022 International Seminar on Computer Science and Engineering Technology (SCSET), IEEE, 2022, pp. 326–329.

[34] W.A. Jabbar, T. Subramaniam, A.E. Ong, M.I. Shu'Ib, W. Wu, M.A. de Oliveira, Lorawan-based IoT system implementation for long-range outdoor air quality monitoring, Internet Things 19 (2022) 100540.

[35] A. Chehri, W. Farjow, H.T. Mouftah, X. Fernando, Design of wireless sensor network for mine safety monitoring, in: 2011 24th Canadian Conference on Electrical and Computer Engineering(CCECE), 2011, pp. 001532–001535.

[36] A. Chehri, P. Fortier, P.-M. Tardif, Security monitoring using wireless sensor networks, in: Fifth Annual Conference on Communication Networks and Services Research (CNSR '07), 2007, pp. 13–17.

[37] M. Wenbin, Y. Yanzhu, H. Yun, Design and application of stepper motor control system, Electr. Appl. 41 (11–13) (2015).

[38] Z. Zhao, X. Qi, Research on Bang-Bang+PID dual-mode control of bullet-Borne electro-hydraulic servos, Autom. Expo 27 (72–75) (2010).

[39] S. Din, A. Paul, S.H. Ahmed, A. Ahmad, G. Jeon, A multi-layer low-energy adaptive clustering hierarchy for wireless sensor network, in: 2017 IEEE 19th International Conference on E-Health Networking, Applications and Services (Healthcom), IEEE, 2017, pp. 1–6.