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Design of wireless control system for crop precision irrigation

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ABSTRACT

In order to improve the utilization rate of agricultural irrigation water, the precision irrigation system based on Internet of things is applied into farmland. Sensor technology, computer technology, wireless communication, and the Internet are combined through the Internet and sensors. Using the Internet of things technology, the control system based on the Internet of things and the networking is established to provide remote farmland irrigation information monitoring and control services for users. Taking ZigBee as the core to build system, the moisture sensor is used for real-time monitoring and automatic irrigation of the farmland based on the soil moisture content. In system design, serial port is taken as the main channel for information exchange between ZigBee chip and single chip micyoco (SCM) development board. The SCM processor connects the information to the Internet, and users can check the information collected by the system through the Internet and realize remote control. The experiment shows that the system can reduce the cost of agricultural production and realize remote precision irrigation.

Keywords: Precision irrigation; SCM; ZigBee; Sensors; Soil moisture; Farmland

1. Introduction

The amount of water for agricultural irrigation is large, which accounts for approximately 70% of the total water consumption. For a long time, due to the backwardness of technology and management, there is a great waste of irrigation water, with a utilization rate of only 40%. During the process of crop growth, the demand for water will be different for different crops and the same crop in different growth period. The unreasonable irrigation time and irrigation water will not only affect the output of crops, but also will affect the quality of agricultural products in different degrees. With the continuous development of modern agriculture and improvement, reasonable use of the high degree of automation, economic, and efficient irrigation system not only can improve the utilization of water resources and achieve the goal of saving water, but also can improve the quality and yield of crops, and thus the agricultural modernization and the improvement of people's economic level also play a role in promoting. At present, most of the monitoring systems use the wired communication technologies, such as RS232 bus cable, cost of which is higher, not easy to expand, maintenance cost is higher, and the monitoring range and large artificial dependency, which lead to have great difficulties in practical application. The aim of this study is to introduce the sensor detection technology, ZigBee wireless network technology, global system for mobile communications (GSM) technology, implementation of farmland soil moisture information for automatic data collection, wireless transmission, real-time monitoring, network publishing and remote irrigation, and other functions, which satisfy the need of the agricultural production and solve the shortcomings of traditional monitoring means and many difficulties [1].

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2. Task analysis

2.1. Demand description

Different crops need different amount of water. For example, winter wheat and corn are the two common field crops. During the growth period, the daily water requirement of winter wheat is 3.5–5.5 mm, whereas the daily water requirement of corn is 5–6 mm. The same crops need different amounts of water during different periods of growth. For example, cucumber's growth is divided into seedling stage, flowering period, and harvest period; its seedling period is 5–7 d, and the period of irrigation is 4–6 d. Therefore, proper irrigation is required for crops. Due to economic conditions and technical constraints, most areas are currently controlled by artificial means of irrigation. This method is not convenient and wastes manpower in the larger planting area, and it is not easy to preserve the historical data of humidity. With the progress of modern science and technology, especially, sensor technology, wireless communication technology, and network technology, soil moisture sensors can be made to collect information; then through the network, the information is sent to the gateway, and the gateway sends data through the Internet to a PC or mobile phone. Thus growers can view all the data in real time and provide appropriate water to crops thereby achieving greater economic and social benefits.

According to the characteristics of crop management, from the user's point of view, the design of crop precision irrigation wireless control system needs to have the following functions:

- The data acquisition system needs to be real time, including real time collection, transmission, and feedback while ensuring the accuracy of data collection. It is convenient for users to inquire about the parameters of the moisture of the crops.
- The system needs to work long term in different environments and deal with abnormal conditions, such as environmental change.
- The nodes need to have extensibility; the sensor nodes need to have rich peripheral interfaces, and the system needs to be extended to meet the needs of different situations.
- The remote monitoring software needs to realize the collection and monitoring of the signal, and also the management and comprehensive analysis of the information.
- The system needs to have an alarm function; when the collected humidity parameter value exceeds the threshold, the system needs to trigger alarm mechanism, an alarm message to the user, so that users take corresponding measures in a timely manner.

2.2. Overall scheme

The system is composed of three layers of network: the underlying layer, the wireless sensor network; the middle layer, the GSM network; and the upper layer, the Internet network. The underlying and middle layers connect through the gateway nodes, whereas the middle and upper layers connect through the public telecommunications gateway.

The bottom layer is wireless sensor network, and the sensor nodes are based on ZigBee wireless communication protocol. ZigBee is an emerging short-range, low-speed wireless network technology. It is mainly used for close-range wireless connection. It has its own protocol standard, coordinating communication between thousands of tiny sensors. These sensors require very little energy to relay data from one sensor to another through radio waves, so their communication efficiency is very high. Wireless sensor network nodes have corresponding wireless network protocol (including media access control [MAC] layer, routing, network layer, application layer, etc.) for mutual data communication.

Multiple sensors are used to measure and collect data. The specific location of the sensor can be chosen scientifically to meet the needs of agricultural production [2]. At the same time, the sensor device is numbered as the identity information for transmitting data to the network. In view of the selected sensor equipment, a simple, scientific, and reasonable database is built to store and process the monitored data in a timely manner. The log of equipment work will be recorded so that the users can master it in time. Zigbee technology is a new wireless communication technology and it is suitable for multi-node and unattended farmland information acquisition system. It has the characteristics of micro power consumption, low cost and flexible networking. When designing the ZigBee node deployment plan, the following must be considered: complete coverage of the monitoring area, connectivity of the entire network, minimization of system energy consumption, and maximization of network life.

The middle layer is the GSM network, which is composed of each gateway node. It can complete the functions of information intersection, data storage, instruction sending and receiving, node positioning, and parameter remote setting. GSM networks have features, such as remote transmission distance, strong anti-interference ability, stable sending and receiving of data, and so on. The GSM module uses serial port to communicate with the microcontroller to realize the wireless transmission function of data [3].

The upper Internet network layer consists of the remote server and various clients. The server receives information from each gateway node. It can complete the functions of data parsing, processing, storage, query, statistics, chart rendering, and network publishing. It can send control instructions to the underlying sensor node through the gateway node to complete the remote parameter setting. The client can monitor the information in real time and remotely set the parameters as long as he/she is logged into the server regardless of the time and place where he/she is, knowing these can be done in the remote parameter setting function in the Web client of sensor nodes.

The data acquisition part is controlled by the microprocessor, which controls the data collected by each sensor, and then the digital information is changed after the analog to digital conversion. The data are preprocessed in the microprocessor and then transmitted to ZigBee via the serial peripheral interface (SPI) communication protocol. The ZigBee module that ported the protocol stack, Z-Stack, sends the data to the gateway node.

ZigBee module receives data from the data acquisition part. According to ZigBee agreement, the processor collects the parsed data via a serial port, processes them, and through the SPI communication protocol, transmits them to the GSM module where they are forwarded to the remote server through the Internet.

The data should be sent to the remote server and then to the gateway where, according to defined data formats, the date are parsed, stored, displayed, the threshold value is set, and alarm triggering mechanism is activated; when data exceed the threshold value, the alarm is triggered. After the user receives an alarm message via the phone, he can send commands to the system remotely via Short Message Service (SMS), start irrigation equipment and make irrigation [4].

3. System design

3.1. Hardware design of precision irrigation control system for crops

3.1.1. Hardware platform

The soil moisture monitoring system is mainly based on STC89C52 single-chip microcomputer. The system includes data acquisition module, data processing module, GSM transmission module, human-computer interaction module, power module and so on, realizing automatic acquisition. Soil moisture information, real-time display, wireless transmission, and finally achieve irrigation control [5]. The overall structure of the system is shown in Fig. 1.

The system mainly realizes automatic collection and intelligent control of soil moisture in a wide area, and the data are directly stored in a fixed storage. It can achieve 24 h continuous uninterrupted real-time monitoring and effective control. The main functions are as follows:

- Collects soil moisture data in real time through sensor.
- Displays the collected data, system time, GSM short information transmission status, and receives user feedback information through the liquid crystal module in real time.
- According to the presetting of the water requirement of different crops, the single-chip microcomputer controls the solenoid valve to start the water pump regularly to achieve the timing quantitative irrigation.
- GSM module sends the soil humidity information text to the user, then receives the user's mobile text message command to decode, and uses the fuzzy control technology to achieve precise irrigation.
- The power module is designed for dual power supply mode, which can realize the switching between solar power supply and battery power supply.

3.1.2. Information acquisition module

The FC-28 soil humidity sensor is the core of information acquisition module. Its internal integration of the potentiometer, which can be adjusted through the threshold of the soil moisture by the potentiometer, can also control the function through software compensation [6].The surface is plated with nickel, with a wide sensing area, which can improve the conductivity and prevent the contact of soil, which prevents it from easily rusting, thus prolonging the service life. It has both digital and analog output modes, with built-in LM393 comparator with strong stability. It is integrated with power indicator and digital quantity switch indicator with a working voltage of 3.3–5 V.

3.1.3. CC2430 wireless module

CC2430 is used as ZigBee chip. The chip still retains the structure of previous CC2420 chips and focuses on radio frequency (RF) front end, memory, and microcontroller on a single chip. A single chip can meet the needs of transmission, which greatly improves the cost performance of the whole system and meets the system requirements of low energy consumption and low price. This chip integrates RF transceiver and 8051-type controller with high performance and full functions. The chip can convert a received signal to a frequency. After second signal processing, it is converted to a digital signal that can be adopted, which greatly improves the accuracy in the conversion process. The module has the following features:

CC2430 uses an 8-bit microprogrammed control unit (MCU) (8051), with 32/64/128 KB programmable flash memory and 8 KB RAM, also contains the analog-to-digital converter, several timers, either AES128 coprocessor, the watchdog

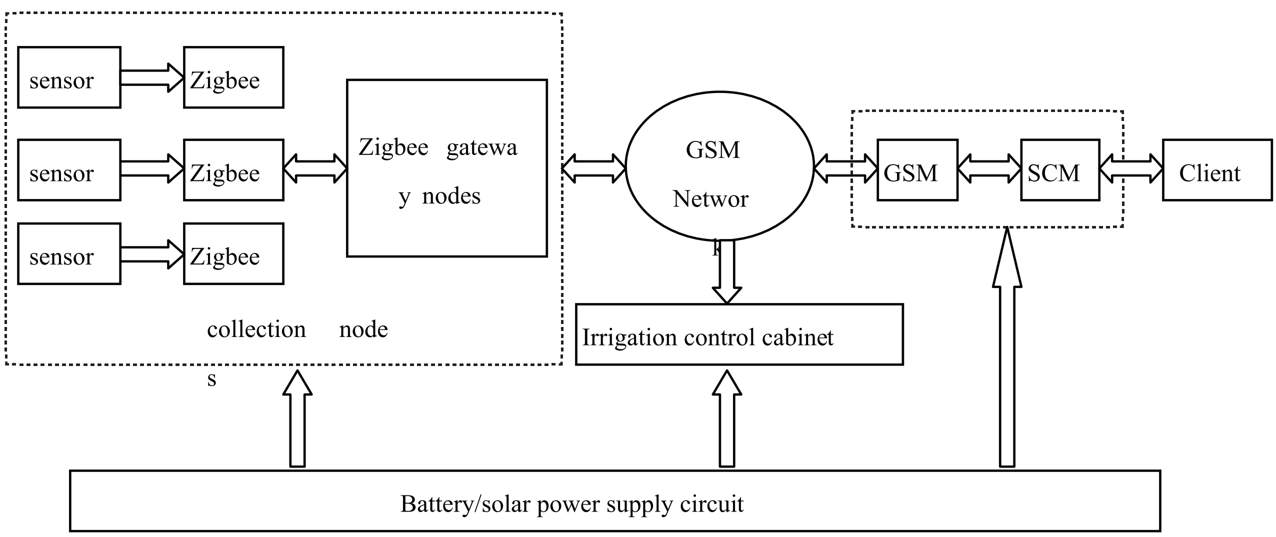

Fig. 1. Hardware structure of precision irrigation control system for crops.

timer, 32 kHz crystals sleep mode of the timer, power on reset circuit, power detection circuit (brown-out detection), and 21 programmable I/O pins. The chip of CC2430 is produced by 0.18 mm complementary metal-oxide-semiconductor transistor (CMOS) technology, and the current loss at work is 27 mA. In the receiving and transmitting mode, the current loss is less than 27or 25 mA, respectively. The dormancy mode of CC2430 and the transition to the active mode of super short-time features are particularly suitable for applications requiring very long battery life. In the suspended mode, the current consumption is less than 0.6 μA, and the external interrupt can wake up the system [7].

The communication distance is short. For example, in home indoor environment, the general communication distance is less than 100 m, which can meet the needs of the monitoring environment for a long time.

The integration of the 8051 controller expands its function, which can meet more design requirements within the established protocol framework. The application principle of CC2430 is shown in Fig. 2.

3.1.4. The GSM module

GSM, the global mobile communication system, is a mobile communication standard. This system uses GSM chip as TC35 module. The TC35 chip is produced and rolled out by Siemens and can work with a voltage range of 3.3–5.5 V, which can work in two frequency bands, 900 and 1,800 MHz [8]. The power consumption in the 900 MHz band is 2 W, and the power consumption in the 1,800 MHz band is 1 W. It can realize data transmission, voice transmission, SMS, and facsimile. The module has the attention (AT) instruction set interface, which can use the AT instruction to communicate, and the encoding of SMS supports text and protocol data unit (PDU) mode.

The normal operation of the TC35 module requires the corresponding peripheral circuit and its coordination. The TC35 has 40 pins, which are connected with the power supply circuit, The control signal of the power transistor in the ignition (IGT) startup circuit, subscriber identity module (SIM) card connection circuit, and SYNC indicator light display status circuit by zero resistance connector. The TC35 module circuit is shown in Fig. 3.

3.1.5. Single-chip computer main control center module

STC89C51RC single-chip microcomputer as the control core is used to complete the communication with the GSM module and the communication with the ZigBee gateway node. In order to save resources, the single-chip microcomputer of the main control center needs to communicate with the above module to simulate serial communication.

In addition, the STC single chip and GSM module TC35 chips need to be switched on the level, and the MAX3222 is used for the level conversion [9].The T1IN of MAX3222 is connected to the G_TXD of the TC35 module, and R1OUT is connected to G_RXD. The MAX3222 T2IN is attached to the MCU_TXD1 pin of the MCU, and R2OUT is connected to the MCU_RXD1 pin. The MAX3222 pins are shown in Fig. 4.

3.1.6. Power supply module

Solar panel absorbs sunlight and converts the solar radiant energy directly or indirectly into electrical energy through the photoelectric effect or photochemical effect, which is relative to the average battery and circulating rechargeable batteries. Solar cells belong to more energy conservation and environmental protection green products. In 2008, researchers of Rensselaer Polytechnic Institute in the United States developed a new type of coating for the solar panels, which can increase the sunshine absorption rate to 96.2%, whereas the sunlight absorption rate of common solar panels was only 70% or so.

In this system, all sensors and solenoid valve control nodes are powered by solar energy devices. This method can solve the problem of the farmland that is far from the power supply of the public power grid.

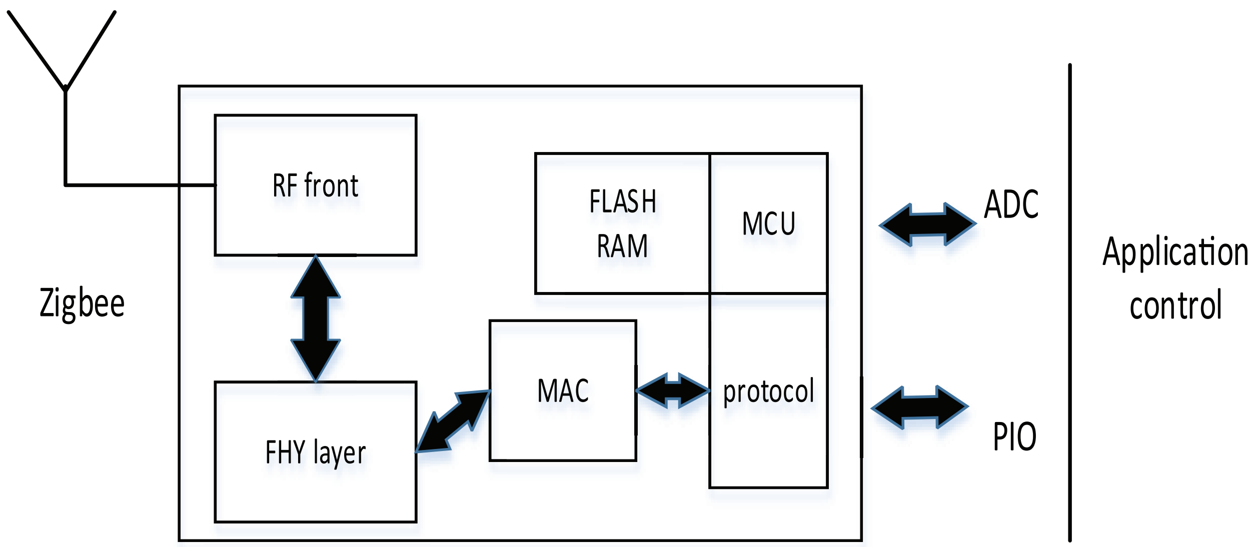

Fig. 2. ZigBee application principle.

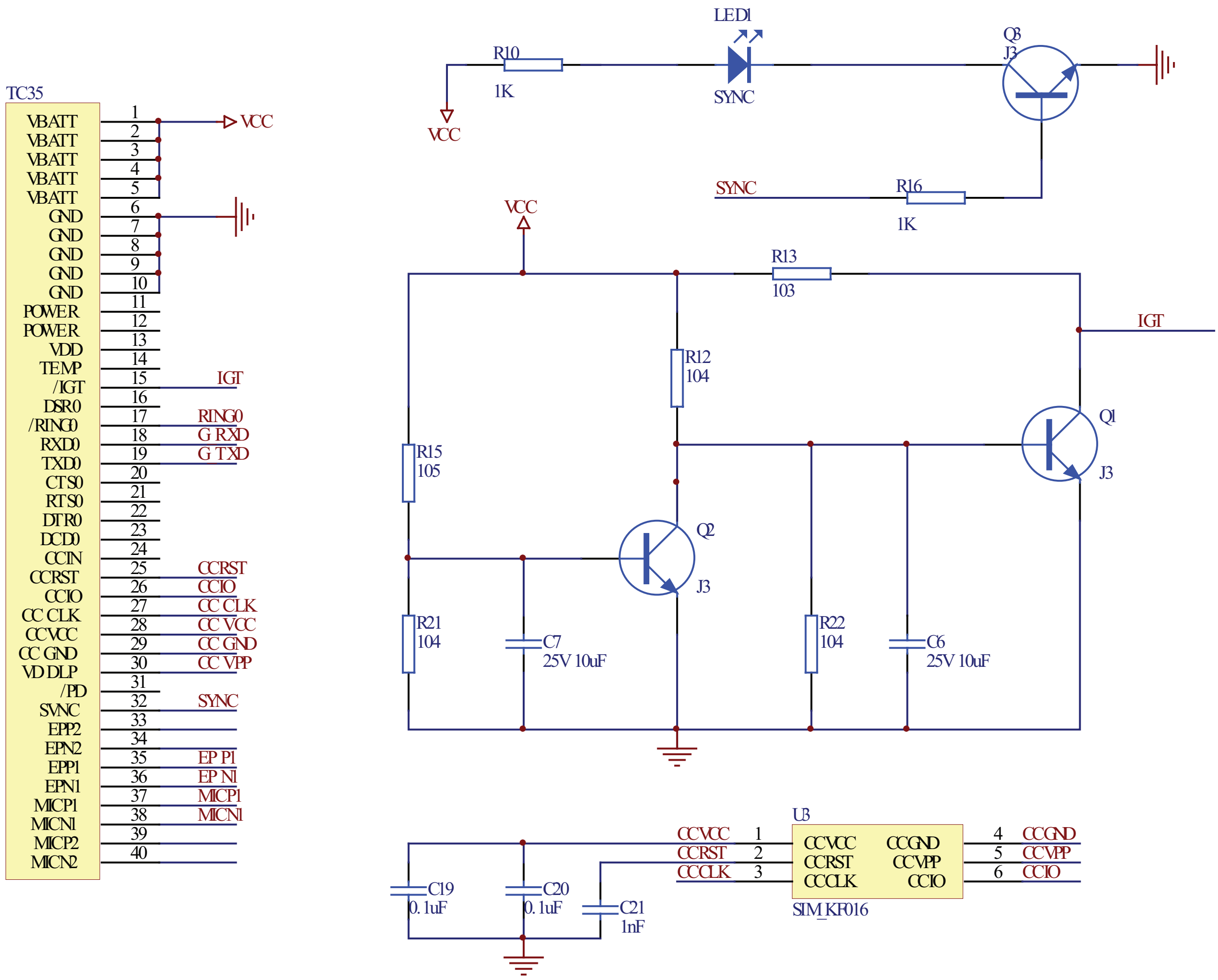

Fig. 3. The TC35 module circuit.

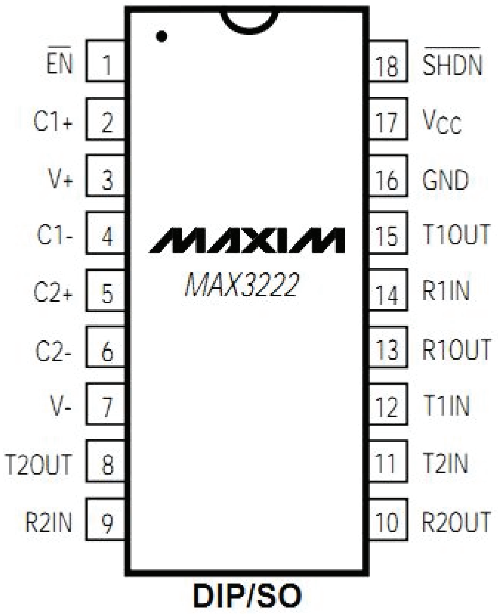

Fig. 4. The MAX3222 pins.

In addition, the system can be simplified and miniaturized by using the solar panel to power the nodes, so that the equipment can be easily installed, dismantled, and moved. The control node in the installation is a small solenoid valve of 12 V and 4.3 W, and the selected battery has a capacity of 120,000 mAh, so the system can be filled for over 10 h continuously [10]. The voltage of the solar panel must be charged by the solar charging controller to reduce and stabilize the charging voltage, so that the battery can be charged and managed. The solar battery charging is shown in Fig. 5 [11].

3.1.7. Irrigation control cabinet

For the convenience of operation, the irrigation controller has only two control buttons: start and stop. Control cabinet has two modes, namely manual control and automatic control, switching between two patterns by liquid crystal display touch screen. Manual control mode is designed for ordinary operators, where the operators can press the start button to start the equipment directly for irrigation, or press the stop button to stop the irrigation [12]. In the automatic irrigation mode, operators can use software systems or mobile phones to start or stop the equipment and convert it to manual control. If there is no operator to send commands, the software system can work in automatic mode; it will make independent decisions according to the results of the soil moisture monitoring and automatic control process of irrigation.

Control cabinet includes single-chip microcomputer, GSM module, LCD touch screen, programmable logic controller (PLC), etc. GSM module, single chip micyoco (SCM), and main control module are of the same type. SCM and GSM module are integrated on a circuit board, forming a remote control unit (RCU), to know the remote control function. PLC is from SIEMENS Ltd., Germany (PLC-CPU224 module). Solenoid valve, sediment delivery device, and flow meter are connected outside the control cabinet. The irrigation control cabinet structure is shown in Fig. 6.

RCU complete the information by the way of SMS transceiver through the GSM module. The GSM module receives control instruction and transmits to MCU to complete parsing work instructions. Control instruction is mainly divided into irrigation instructions and status query. Irrigation command is used to start or stop the irrigation. Status query directives are used to query the irrigation. PLC controller is used to control electromagnetic valve switch and eliminate the sand control device. At the beginning of the irrigation, the water contains a lot of sand, and therefore a sieve control device needs to be set out. Sand control module is used to start the pump with the relay, and the sand removal, irrigation electromagnetic valve closed at this time. After the sand is filtered, the electromagnetic valve is opened and irrigation begins according to the instructions.

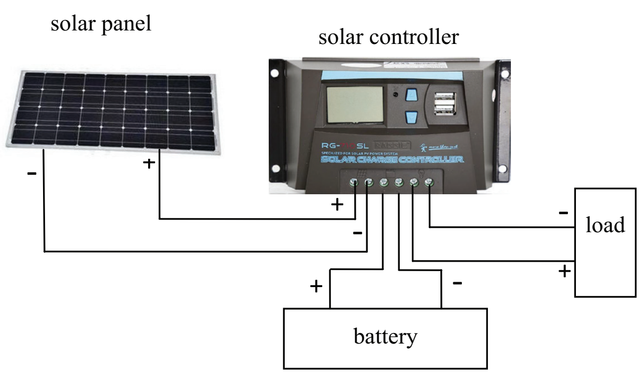

Fig. 5. Solar battery charging.

3.2. *Software design of precision irrigation control system for crops*

3.2.1. *Software system requirements analysis*

System software design is the core of the wireless control system of crop precision irrigation. The software system enables the gateway and terminal nodes to be tightly integrated together, and it ensures that the system can be carried out at high speed and efficiency, which achieves the purpose of automatic irrigation.

In the software system, it is necessary to manage the equipment, system parameters, data acquisition and expert knowledge of the system, and realize the autonomous decision-making of irrigation system. System management, mainly included user management, parameter setting, data backup and recovery, and so on. Equipment management included sensor number, node location, node sensor management, etc [13].

3.2.2. *Data acquisition program design*

Data acquisition is mainly through the software system which sends a collection instruction to the terminal node that will return to PC collecting the results after the PC processes the data saved to the database [14].

The terminal node is mainly responsible for collecting data of soil humidity sensor. At work, the terminal node must first join the network, and the node will automatically bind to the coordinator or routing node of the first response, before transferring the data information. The terminal acquisition node is not always working, and when the terminal acquisition node does not receive and send data, it is set to sleep to minimize the power consumption. The design of data acquisition program is shown in Fig. 7.

3.2.3. *Design of irrigation control procedures*

The software system can be used for irrigation by means of automatic irrigation or artificial control. First, the irrigation control mode is set in the software system, and the system is timed to check whether there are any irrigation tasks that need to be performed. If there is a planned task that needs to be performed, then check whether there is an ongoing irrigation task [15]. If a task is being carried out, the alarm information will be generated. Instead, the irrigation control instructions are sent to the irrigation control equipment. After the control cabinet receives irrigation instructions, open the solenoid valve to start irrigation. The design of irrigation control procedures is shown in Fig. 8.

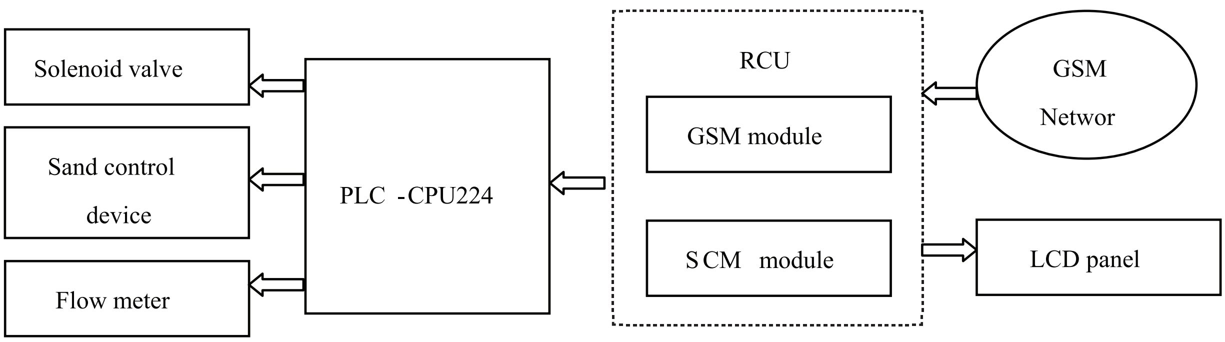

Fig. 6. Irrigation control cabinet structure.

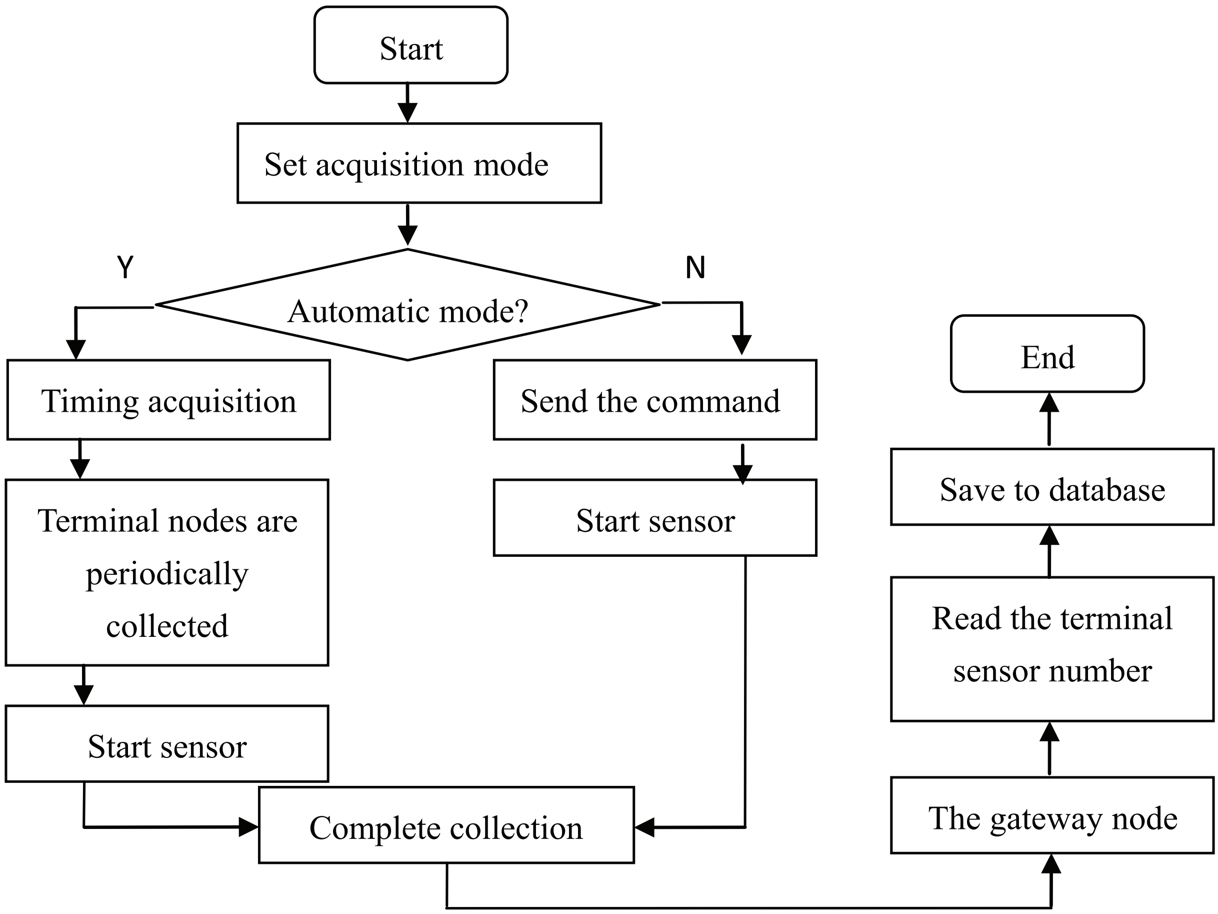

Fig. 7. The design of data acquisition program.

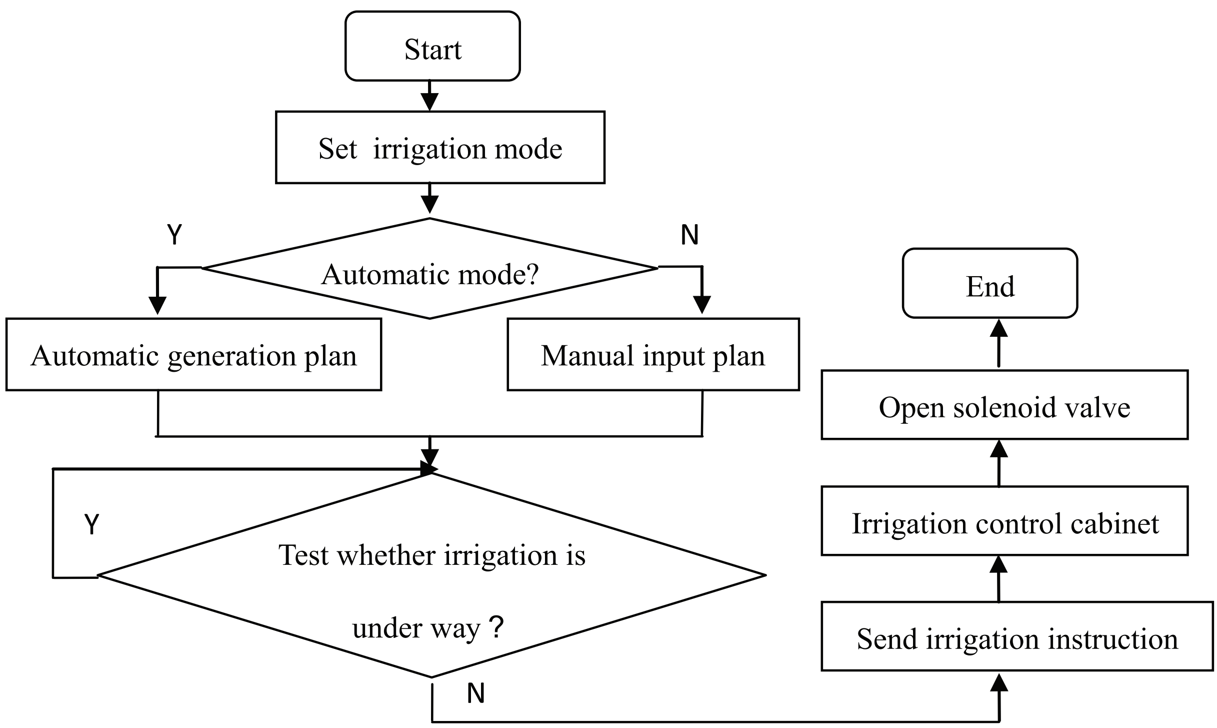

Fig. 8. The design of irrigation control procedures.

4. Conclusion

The technical background of the project is analyzed, and the specific function of the system is studied. The overall solution is built in the current mainstream design type. Using ZigBee wireless network, GSM remote data transmission module, MCU efficient processing technology, and solar power technology, the automatic irrigation control system for crop production and management is set up by the soil humidity parameters acquisition, man–machine interface through the upper machine manual, automatic control, and opening of electromagnetic valve for irrigation. It greatly improves the utilization rate of water resources and meets the requirements of precision agriculture. The development of system software has been completed, and the system function has been tested accordingly. In conclusion, the wireless control system of crop precision irrigation is consistent with the development of current environmental information technology and the rational utilization of water resources. Through simple hardware collocation and software design, soil moisture information of farmland can be obtained, remote control irrigation can be achieved, and specific information data can be collected.

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