# Chapter 2
# Agricultural Internet of Things

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## 2.1 Agricultural Internet of Things Concept

### *2.1.1 Basic Concepts and Common Technologies of the Internet of Things*

The concept of Internet of Things (IoT) was first proposed by the Massachusetts Institute of Technology in 1999. The early IoT, based on radiofrequency identification (RFID) technology and equipment, refers to the network according to the agreed communication protocol, which enable intelligent identification and management of item information to achieve interconnection, exchangeability, and sharing of item information. With the development of technology and application, the connotation of the IoT has been expanded and redefined as follows. IoT is the expanded application and network extension of communication network and Internet, which uses perception technology and intelligent devices to perceive and identify the physical world. Through network transmission interconnection, IoT performs calculation, processing, and knowledge mining to achieve human–object and object–object information interaction and seamless linkage. The goal is to achieve real-time control, precise management, and scientific decision-making over the physical world (ITU Internet Reports, 2005); Internet of Things in 2020, 2008).

The IoT network architecture consists of perception layer, network layer, and application layer, as shown in Fig. 2.1. The perception layer includes perception and control sub-layer and communication extension sub-layer. The perception and control sub-layer can realize the intelligent perception and recognition, information

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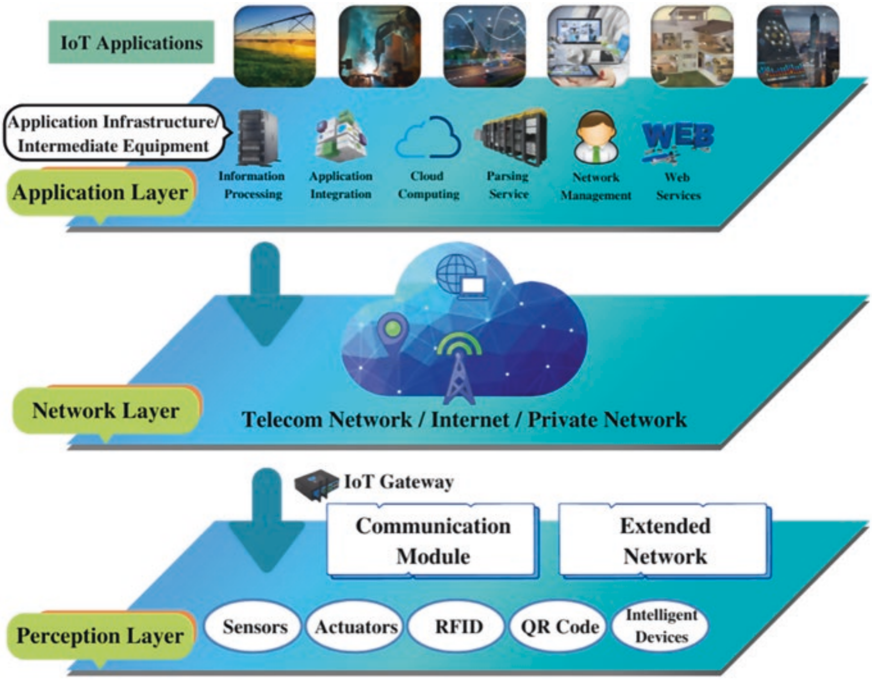


**Fig. 2.1** IoT network architecture

collection and processing, and automatic control of real world. The communication extension sub-layer connects physical entities to the network layer and application layer through communication terminal modules directly or after forming an extension network. The network layer includes the access network and the core network, which can realize the transmission, routing, and control of information. The network layer relies on the public telecommunication network and the Internet, as well as the industry-specific communication network. Application layer includes application infrastructure/middleware and various IoT applications. Application infrastructure/middleware provides basic service facilities and resource invocation interfaces for IoT applications, so IOT can be applied in many fields.

The extension of the network to the physical world is a prerequisite for the existence of the IoT.

Therefore, for any extended IoT application, it must rely on the technology of perception level. The common key technologies of IoT mainly include the following areas: perception, control, network communication, microelectronics, computer, software, embedded system, micro-electromechanical, and other technologies. Among them, sensor and RFID technology belong to the first step for the IoT to receive information from physical world. In order to systematically analyze the IoT technology system, the key technologies of IoT can be categorized into the following aspects: perception, network communication, application, network common technologies, and supporting technologies, as shown in Fig. 2.2.

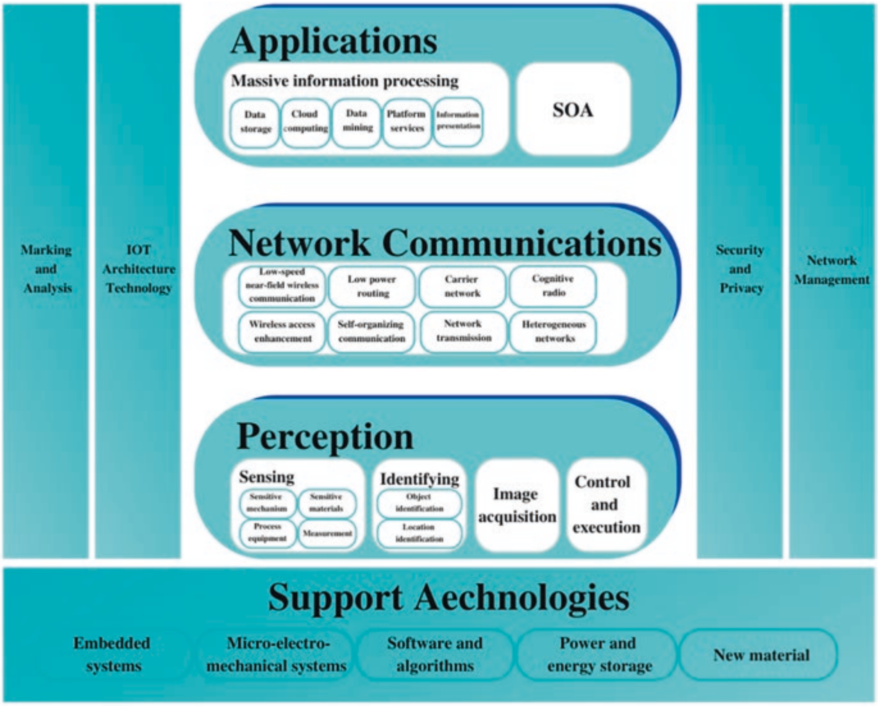


**Fig. 2.2** IoT key technologies

### *2.1.2 Agricultural Internet of Things Concept*

The European Smart Systems Integration Technology Platform submitted Internet of Things–Strategic Research Roadmap in 2009, which divided the IoT into 18 major categories. Among them, "Internet of Things in Agriculture and Farming" is one of the most important development directions (Commission of the European Communities, 2009; Internet of Things, 2009). According to the report, agricultural IoT is divided into three layers: information perception, information transmission, and information application. The information perception layer consists of various sensor nodes. Through advanced sensor technology, a variety of parameters to enhance agricultural refinement management can be obtained, such as soil fertility, crop seedling growth, individual animal productivity, health, behavior, and other information. In the information transmission layer, various types of data obtained by sensors are released to the local area network and wide area network through wired or wireless communication protocols. The information application layer fuses and processes the data for making scientific management decisions and controlling the agricultural production process.

The IoT in agricultural application will face a series of scientific and technological problems such as the acquisition of information distributed in a wide area, efficient and reliable information transmission and interconnection, and the integration of intelligent decision systems for different application requirements and environments. The breakthrough of key generic technology in electronic, information, communication technology and industry and the support from low cost, convenient, and easy-to-use hardware and software products and services are strongly needed. Besides, technology integration and operation service mode innovation about agricultural application with agriculture biology, information and equipment engineering scientists' efforts are also required. Information technology will be integrated into various agricultural application fields and become the link between biological, agronomic, and engineering. The innovation of IOT agricultural application will break the boundaries of disciplines and departments, promote intersection and integration of different disciplines, generate new cross-disciplines, and vigorously promote the demand and application oriented collaborative research model, creating new opportunities for the development of new industries and the transformation of agricultural development.

Faced with the dual constraints of resource scarcity and ecological environment deterioration, the contradiction of high resource input and sloppy operation, and the serious challenge of quality and safety of agricultural products, the development of modern agriculture urgently needs to strengthen the application of agricultural information technology represented by agricultural IoT to realize real-time monitoring of agricultural production factors from macroscopic to microscopic in the process of agricultural production, improve the level of fine management of agricultural production and operation, and achieve the purpose of rational use of agricultural resources, reduce production costs, improve the ecological environment, and improve the yield and quality of agricultural products. Based on the principle that information can be perceived at any time, any place, and anything, IoT can support refined process management according to the information and knowledge in all links of agricultural production. In pre-production, IoT can be used to monitor and evaluate agricultural resources such as farmland, climate, water resources, and agricultural materials in real time, providing a basis for scientific utilization and supervision of agricultural resources. In production, IoT can be used to monitor the production process, input use, environmental conditions and implement fine regulation of agricultural production action. In post-production, IoT can be used to connect agricultural products with consumers, so that consumers can transparently understand the production and supply process from the farm to the table. IoT promote the development of e-commerce of agricultural products.

## 2.2 Basic Technologies for Agricultural IoT

### *2.2.1 Agricultural Information Sensing Technology*

Agricultural information sensing technology refers to the use of agricultural sensors, radiofrequency identification (RFID), bar codes, global navigation satellite systems (GNSS), remote sensing (RS) technology, etc. to collect and acquire information on objects in the agricultural field at any time and any place.

### Agricultural Sensors

Agricultural information sensing technology is the core of agricultural IoT. Agricultural sensors are mainly used to collect information in various agricultural applications, including parameters such as light, temperature, water, fertilizer and gas in planting industry; harmful gas content of carbon dioxide, ammonia, and sulfur dioxide, concentration of dust, droplets and aerosols in air, environmental indicators such as temperature and humidity in livestock and poultry breeding industry; dissolved oxygen, pH, ammonia nitrogen, conductivity, and turbidity in aquaculture industry. The first section of this chapter describes several typical agricultural sensors in detail.

### Radiofrequency Identification Technology

Radiofrequency identification (RFID), known as electronic tags, refers to the use of radiofrequency signal through space coupling (alternating magnetic field or electromagnetic field) to achieve contactless information transmission and through the information transmitted to achieve the purpose of automatic identification (Finkenzcller, 2003; van Kranenburg, 2008). RFID, emerging from the 1990s, can automatically identify the target through radiofrequency signals and obtain relevant data. The identification process without manual intervention can work in a variety of harsh environments. RFID is mainly used in agriculture in animal tracking and identification, digital breeding, fine crop production, agricultural circulation, etc. (Jeffery et al., 2006; Weizhu et al., 2010).

RFID system is composed of reader, electronic tags, and application software (van Kranenburg, 2008). RFID system working principle diagram as shown in Fig. 2.3. After the electronic tag into the magnetic field, reader transmits a specific frequency of radio wave energy to the electronic tag to drive the electronic tag. By the energy obtained from the induction current, electronic tags send internal data stored in the chip (passive tag or passive tag). Or the tag actively sends a signal at a certain frequency (active tag or active tag). The reader reads and decodes the information and sends it to the central information system for data processing. In terms of communication and energy sensing between RFID reader and electronic tag, it can be roughly divided into two categories including inductive coupling (Inductive Coupling) and backward scattering coupling (Backscatter Coupling). The general low-frequency RFID mostly uses the first type, while the higher frequency mostly uses the second way.

### Barcode Technology

Barcode technology is an automatic identification technology integrating barcode theory, photoelectric technology, computer technology, communication technology, and barcode printing technology. Barcode, made up of strips (black, white, and

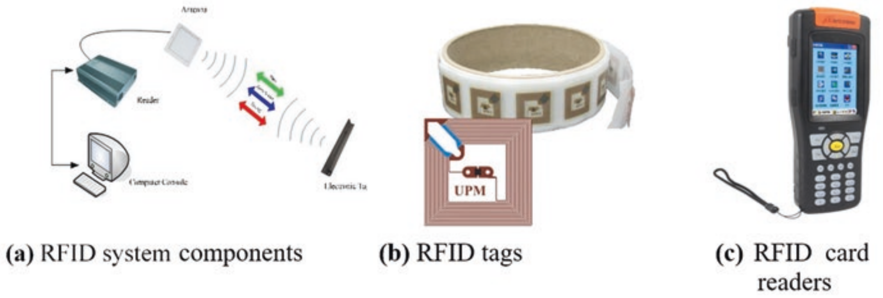


**Fig. 2.3** RFID system working principle diagram. (**a**) RFID system components; (**b**) RFID tags; (**c**) RFID card readers

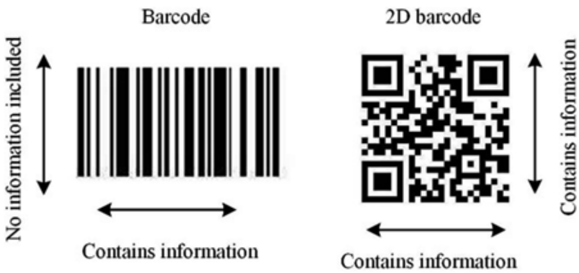


**Fig. 2.4** Schematic diagram of 1D barcode and 2D barcode

empty color) with different width and reflectivity according to certain coding rules, is used to express a group of numbers or letters. Barcode technology has been widely used in the quality traceability of agricultural products.

The barcode is divided into one-dimensional (1D) code and two-dimensional (2D) code. Among them, the 1D code is composed of vertical black and white stripes with different thickness. Usually there will be English letters or Arabic numerals under the stripes. 2D code is usually a square structure, not only consists of horizontal and vertical bar codes, and there are also polygonal patterns within the code area. And the texture of the 2D code is also black and white with different thickness. The 2D code is in the form of dot matrix. As shown in Fig. 2.4, the 1D code only contains information in the horizontal direction, the storage capacity is limited, and only numbers could be stored, which could be only used to identify the basic information of goods, such as product name, price, etc. To invoke more information, it is needed to cooperate with the computer database. 2D code, containing information in both horizontal and vertical directions, provides large storage capacity. 2D code can be composed of Chinese characters, letters, numbers, and other information, so it not only has a special identification function but also can display more detailed product content.

### 2.2.2 Agricultural Information Transmission Technology

Agricultural information transmission technology refers to the access of agricultural objects to the transmission network through sensing devices providing the highly reliable information interaction and sharing anytime and anywhere with the help of wired or wireless communication networks. Agricultural information transmission technology can be divided into wireless sensor network technology and mobile communication technology.

#### Wireless Sensor Network Technology

Wireless sensor network (WSN) is a self-organizing multi hop network system formed by wireless communication. It is composed of a large numbers of sensor nodes deployed in the monitoring area, which are responsible for sensing, collecting, and processing the information of the perceived object in the network coverage area and sending it to the observer (Suman Kumar et al., 2009; Wang et al., 2006).

The typical WSN structure is shown in Fig. 2.5, including sensor node, gateway node, and monitoring software. A large numbers of sensor nodes are distributed in the monitoring area and form a wireless network through self-organization. The data monitored by the sensor node is transmitted hop by hop along other sensor nodes. In the transmission process, the monitoring data may be processed by multiple nodes, routed to the gateway node after multiple hops, and finally transmitted to the monitoring software through Internet, satellite, and other communication methods. Users can configure and manage WSN through monitoring software, publish monitoring tasks, and collect data.

Sensor node is usually a micro embedded system with relatively weak processing, storage, and communication capacity, which is usually powered by battery with limited energy. From the perspective of network function, each sensor node has the dual functions of terminal and router of traditional network nodes. In addition to

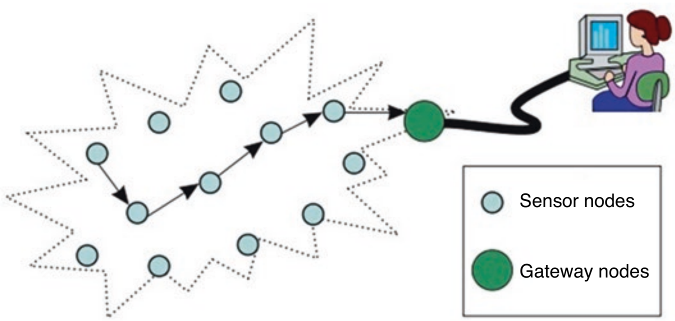


**Fig. 2.5** Schematic diagram of wireless sensor network structure

local information collection and data processing, it also needs to store, manage, and integrate the data forwarded by other nodes, and cooperate with other nodes to complete some specific tasks. The gateway node has relatively strong processing, storage, and communication capacity. It is the link connecting WSN, the Internet and other external networks, who realizes the communication protocol conversion between the two protocol stacks, releases the monitoring tasks of the management node, and forwards the collected data to the external network. The gateway node can be either a sensor node with extra functions, with sufficient energy supply, more memory and computing resources, or a gateway device only acting as a wireless communication interface without monitoring capacity. The monitoring software is used to monitor the changes of WSN data information in real time for further analysis and processing according to the collected data information, so as to dig out more valuable information for guiding production practice.

ZigBee technology, based on the IEEE802.15.4 standard, is a technology standard on wireless networking, security, and other applications. ZigBee is widely used in the formation of wireless sensor networks, such as field irrigation, agricultural resource monitoring, aquaculture, agricultural product quality traceability.

### Mobile Communication Technology

With the improvement of agricultural informatization level, mobile communication has gradually become an important and key technology for long-distance transmission of agricultural information. Mobile communication has gone through five generations of development. The first-generation mobile communication system (1G) was proposed in the early 1980s, mainly based on cellular structure network, directly using analog voice modulation technology, transmission rate of about 2.4 kbit/s. The second-generation mobile communication system (2G) originated in the early 1990s, using more intensive frequency multiplexing, multiplexing, multiple reuse structure technology, the introduction of smart antenna technology, dual-band, and other technologies. The introduction of GPRs/EDGE technology enabled the organic combination of GSM and computer communication/Internet with data transmission rates up to 115/384 kbps, thus enabling GSM functions to be continuously enhanced and initially equipped with the ability to support multimedia services. The third-generation mobile communication system (3G), also known as IMT 2000, the most basic feature is intelligent signal processing technology, intelligent signal processing unit will become the basic functional module to support voice and multimedia data communications, it can provide a variety of broadband information services that cannot be provided by the first two generations of products, such as high-speed data, slow images and television images. The fourth-generation mobile communication system (4G), which integrates 3G and WLAN and is capable of downloading at 100 Mbps, 2000 times faster than dial-up, and uploading at 20 Mbps. The fifth-generation mobile communication system (5G) adopts a new service-oriented architecture to support flexible deployment and differentiated service scenarios. 5G is capable of downloading at 10 Gbps. The latency of air interface is as low as 1 ms, which can meet real-time applications such as automatic driving and tele-diagnosis.

### 2.2.3 Agricultural Information Processing Technology

Agricultural information processing, as one of the key technologies of the IoT, is based on agricultural information knowledge and adopts various intelligent computing methods to make objects possess certain intelligence and be able to communicate with users actively or passively. Agricultural information processing technology includes agricultural prediction and early warning, agricultural optimal control, agricultural intelligent decision-making, agricultural diagnostic reasoning, agricultural visual information processing, etc.

#### Forecasting and Early Warning Technology for Agriculture

Agricultural forecasting is based on actual agricultural information such as soil, environment, meteorological data, crop or animal growth, agricultural production conditions, fertilizers, pesticides, feeds, aerial or satellite images, economic theory and mathematical models, to speculate and estimate the possibility of future development of the research object. Agricultural early warning is to measure the future state of agriculture, forecast the time and space range and harm degree of unusual state, and put forward preventive strategies (Handcock et al., 2009).

#### Intelligent Control Technology for Agriculture

Agricultural intelligent control is to synthesize and integrate various disciplines such as artificial intelligence, cybernetics, system theory, operational research, and information theory under given constraints in the agricultural field, so that the given performance index of the controlled system can be controlled intelligently.

#### Intelligent Decision-Making Technology in Agriculture

Intelligent decision-making in agriculture is a specific application of intelligent decision support systems in agriculture, which integrates the knowledge, data, and operations in artificial intelligence (AI), business intelligence (BI), decision support systems (DSS), agricultural knowledge management systems (AKMS), agricultural expert systems (AES), and agricultural management information systems (AMIS).

#### Agricultural Diagnostic Reasoning Techniques

Agricultural diagnosis refers to the process in which agricultural experts identify the objects based on their characteristic information and use certain diagnostic methods to determine whether the objects are in a healthy state, identify the corresponding causes, and propose ways to change the state or prevent its occurrence, so as to make an objective and realistic conclusion about the object state. Agricultural diagnostic reasoning refers to the construction of a causal network diagnostic reasoning model based on "symptom-disease-cause" by using the knowledge representation method of digital representation and functional description.

#### Agricultural Visual Processing Technology

Agricultural visual processing refers to the use of image processing technology to process the collected agricultural scene image to realize the recognition and understanding of the target in the agricultural scene. The basic visual information includes brightness, shape, color, texture, etc.

## 2.3 Agricultural IoT Applications

### *2.3.1 Application of IoT in Agricultural Information Monitoring*

Scientific decision-making and management of the crop growth environment information obtained in real time is an important element of agricultural informatization. Take the "Smart Agricultural Information Platform" supported by China agricultural university as an example, the platform is based on B/S model, consisting of infrastructure layer, data service layer, basic application service layer, service bus layer, business processing layer, and user access layer. It realizes the functions of collecting and storing greenhouse temperature, humidity, light, $CO_2$, and video information, maintaining basic information, analyzing data and outputting alarms. The application results show that the platform has good stability, perfect functions, and a friendly and convenient human–machine interface, which can realize the effective organization and management of data.

#### General System Design

The "Smart agriculture information platform" mainly includes "one platform and four systems," namely smart agriculture information platform and precision farming management system for field crop production, fine facility agriculture management system, fine health breeding management system, and traceability management system for agricultural products. The platform is based on B/S mode, and the system consists of an infrastructure layer, data service layer, basic application service layer, service bus layer, business processing layer, and user access layer. Among them, the infrastructure layer mainly includes the hardware and software foundation for information storage and transmission. The data service layer mainly realizes the integration of different types of data originally distributed in the system. The basic application service layer provides many decomposed application services performing a single function, such as permission management, membership management services, etc. The service bus layer uniformly registers the relatively independent basic service objects on the ESB service bus and manages the service life cycle and service interface invocation rules through the ESB. The business processing layer provides a set of business services with related functions established according to the system user roles. The user access layer displays the single application services, composite business services, and integrated data services provided by the bottom layer of SOA architecture to end users through a unified access portal.

1. System Structure Design

   Taking greenhouse as an example, the data collection and remote transmission subsystem are composed of sensor nodes, gateway nodes, and relay routing nodes. The sensor nodes are connected with temperature, humidity, carbon dioxide, and light sensors and deployed in the center of each greenhouse. The nodes transmit the sensed data to the gateway node in a multi-hop manner through ZigBee wireless communication technology, and the gateway node is connected to a local PC through a serial line, on which the stand-alone monitoring software runs, receives, and stores the monitoring data through serial scanning, then processes and analyzes them. The greenhouse administrator can view the monitoring reality.

   The PC is connected to the server depending on the field situation: the PC is connected to the server via the Internet in areas with network; otherwise, it is connected to the server via GPRS. The stand-alone monitoring software uses TCP/IP protocol to transmit greenhouse environmental monitoring data to the information platform in real time. The server consists of a data receiving and storage program, MS SQL Server database, and the information platform. The data receiving and storage program is responsible for listening to the designated port, judging and recognizing the TCP socket connection request from the terminal of stand-alone monitoring software, and storing the received content into MS SQL Server database if it is legal data. MS SQL Server database is responsible for storing the received data and the required basic information for the information platform to access and call. The information platform processes the data in the SQL database and sends the data to the information platform in the form of graphics and charts. The Web-based information platform is a set of web applications, which adopts ASP.NET dynamic web technology and is developed by Visual Studio.net 2008 development tool and C# language.

The video camera is connected to the server platform and PC via Internet network to monitor the growth of greenhouse crops and pests and diseases.

The server platform system is designed in B/S mode. Users can access this Web application simply through a browser to perform management operations such as querying monitoring data, and authorized users can watch the video monitoring images of each greenhouse in real time. The overall structure of the system is shown in Fig. 2.6.

2. System Function Design

Taking the greenhouse as an example, the software functions of the information platform are divided into five parts: data acquisition, data storage, basic information maintenance, data analysis, and data output. Among them, the data acquisition module adopts TCP socket technology to listen to and receive the data uploaded by the stand-alone monitoring software, and judge whether it is qualified data, and discard it if "no" and store it if "yes." The data storage module can store the received sensor data, historical data of greenhouse, spatial distribution map data, basic information, and user information, etc., which provides the basis for the detailed display and management maintenance of the platform. In the basic information maintenance module, to ensure that users see the latest information, the administrator should update and maintain the basic information at any time, such as setting the standard value with the change of seasons and crops, assigning user rights, updating greenhouse information, etc. The data analysis module can perform statistical analysis on the uploaded data and logically judge whether it exceeds the upper and lower monitoring limits and make a conditional query of data, etc. The data output module can display the uploaded data in real time and output alarm records according to logical judgment.

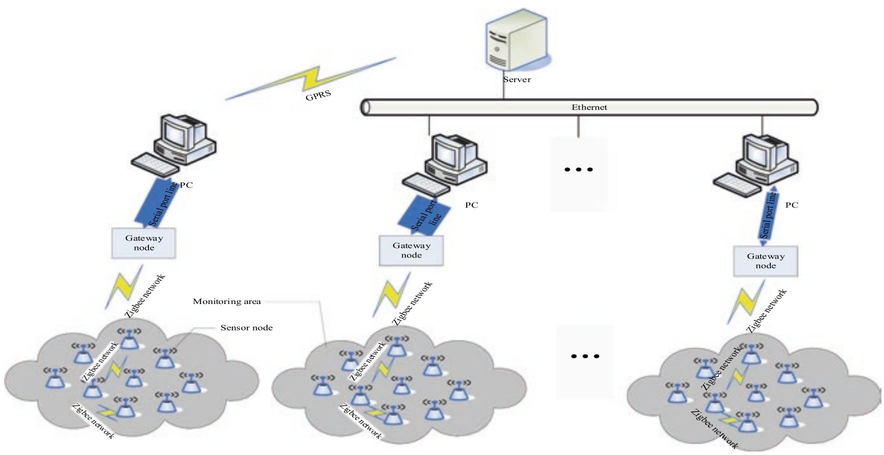


**Fig. 2.6** Overall system structure diagram

### System Flowchart and Database Design

The smart agriculture information platform mainly includes the design of operation flows, data flows, and database tables.

1. Operation Flow Design

   After authorized users log in, they can view release information, monitoring information, data query, reports, etc. according to different permissions. The general users only have the permission to browse the shared information. The administrator is responsible for assigning user permissions, releasing information, and updating the data.
2. Data Flow Design

   Taking the greenhouse management system as an example, the first data flow divides the functional of system and the data connection between each function. The second layer 2 refine the data flow of each module function.
3. Database Design

   Considering that the data volume will become huge as the collection frequency increases and time lengthens, the medium-sized database—SQL, which has advantages in security, concurrency control capability, data mining, and online operation—is selected for storing data.

Since the information platform function includes four systems with complicated functions, the database tables have complex relationships. Therefore, database tables that conform to the third normal form are selected to eliminate data redundancy, update exceptions, insert exceptions, and delete exceptions.

### System Realization

1. Data Storage and Management

   TCP socket technology was used to receive data uploaded by stand-alone monitoring software via Ethernet or GPRS. The database stored the uploaded data and greenhouse environment monitoring standard values, alarm information, basic greenhouse information, user registration information, news information, etc. The system compares the uploaded greenhouse environment monitoring data with the latest monitoring standard values. And if the upper and lower limits are exceeded, alarm information is generated and written in the alarm information table.
2. Data Display and Inquiry

   Curved graphs and tables are used to display real-time monitoring data of each greenhouse node; pie charts and bar charts show greenhouse planting information and greenhouse yield data over the years; tables show greenhouse files, standard values of each greenhouse in different periods, greenhouse planting records, soil information, etc.

### 2.3.2 *Application of IoT in Farmland Moisture Monitoring*

In Northern China, droughts occur frequently. It is necessary to monitor soil moisture and implement drought-resistant irrigation in order to prevent the harm of meteorological drought to the growth of winter wheat. Water resources in China are seriously insufficient, but there still exist some problems such as low utilization and serious waste of water resources. Under such circumstances, how to improve the efficiency of water resource utilization is of special practical significance for the development of modern agriculture. By adopting advanced and applicable information communication and sensor technologies, an agricultural water resources information monitoring system for large field agricultural production is established to realize dynamic and accurate monitoring of agricultural resources, thus promoting scientific management and rational utilization of water resources. Therefore, it is necessary to establish a wireless sensor network-based moisture monitoring system for large fields.

Take the example of the precision agriculture demonstration base in Huantai County, Shandong Province, China. The large field moisture monitoring system adopts a combination of fixed monitoring and mobile monitoring schemes. Two farmlands (0.04–0.067 $km^2$ each) were selected to establish a large field moisture monitoring system. In these two fields, fixed monitoring mode was selected. About 6–10 monitoring nodes were set up to build a field moisture monitoring system through the wireless sensor network. The monitoring nodes converge the collected moisture information to the gateway nodes. Then the gateway nodes use GPRS network or Internet (depending on the site-specific conditions) to send the environmental monitoring information reported by each node to the moisture information management platform to realize the remote collection and monitoring of moisture data. Subsequently, webcams were installed in each of the two farms for monitoring the field sites. The schematic diagram of the system is shown in Fig. 2.7.

#### Sensor Nodes and Gateway Nodes

The sensor node is shown in Fig. 2.8. This node is solar-powered and is responsible for environmental information collection and short-distance data transmission. This node can input up to four analog or digital signals. In this system, only the FDS soil moisture sensor is connected, with an operating voltage of 5–12 V and an operating current of 35 mA. By calibration, the voltage signal output from the sensor is converted to the volumetric soil moisture content.

In the experimental demonstration base, in addition to the node that can monitor soil water content in real time, a weather station node is also installed to measure the weather information of the monitoring area in real time, and the measurement parameters include air temperature and humidity, rainfall, wind speed, wind direction, light intensity, etc. The weather station node and the soil water content node transmit the real-time measured data to the gateway node using near-range wireless communication respectively. And the gateway node completes the remote transmission of the data (Fig. 2.9).

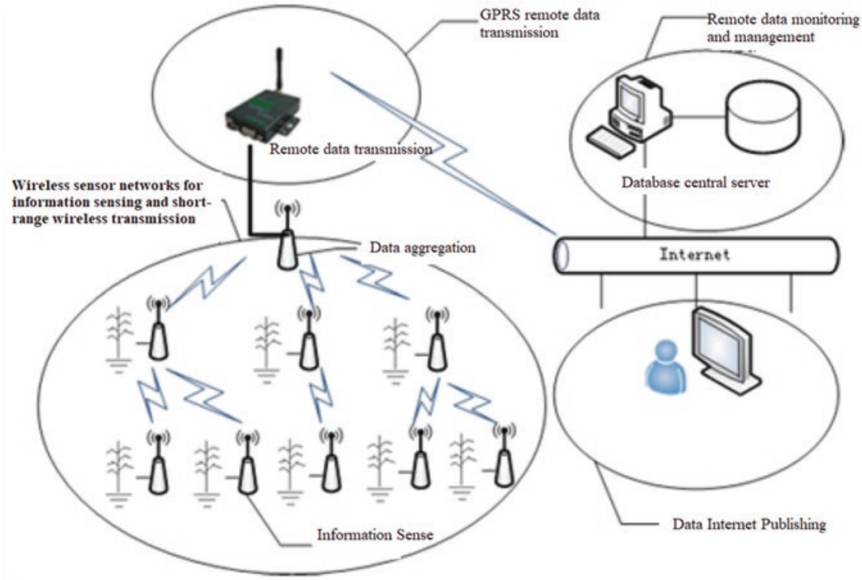


**Fig. 2.7** Schematic diagram of the soil moisture monitoring system based on wireless sensor network

**Fig. 2.8** Sensor node


The gateway node has the same appearance as the sensor node. While compared with the sensor node, the gateway node has extra GPRS DTU (data transfer unit) modules. The gateway node is responsible for converting the collected sensor node data into serial data and sending it to the GPRS DTU, which then sends serial data to the server.

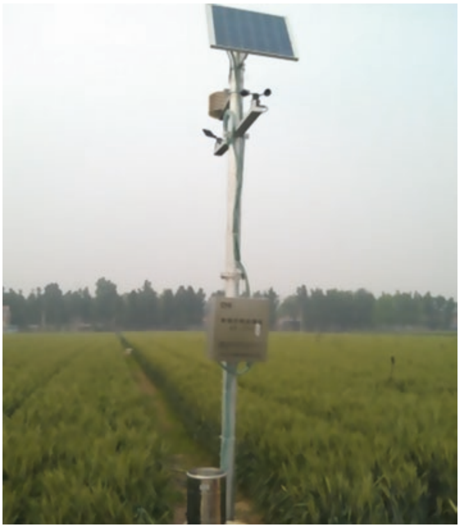

**Fig. 2.9** Weather station node

### Video Information Acquisition and Transmission

In the soil moisture monitoring system, a webcam is installed in each farm for real-time monitoring of the field environment. The video information collected by the camera is forwarded to the server through a pair of wireless bridges. As there are many problems in laying high-speed broadband in the field, wireless bridges can effectively replace wired broadband to achieve high-speed transmission of video information from the field to the server.

In this project, the camera was a D-LINK high-speed dome network camera with high resolution and advanced backlight compensation. This camera could capture clear images even under changing illumination conditions and is equipped with a double-layer protective cover and a built-in integrated cloud platform. The cloud platform control program allows remote control for 360° rotation and flexible focal length adjustment. Waveking wireless outdoor bridge, operating in 5 GHz band, built-in 18 dBi patch directional antenna and plastic shell, supports IEEE 802.11A features and IEEE 802.11A/N standard. The wireless bridge integrates the multi-function of wireless AP (Access Point), point-to-point, and point-to-multipoint wireless bridge, with the highest power of 23 dbm (200 mw), which can realize the working modes of single access point connection, multiple access point connection, etc. The installation diagram of the network camera and the wireless bridge is shown in Fig. 2.10. The camera and the bridge of the sending end are installed on the bracket in the farmland. This bridge is responsible for the acquisition and sending of video information. The bridge of the receiving end is installed on the outer wall of the experiment station and is connected to the server by wired method.

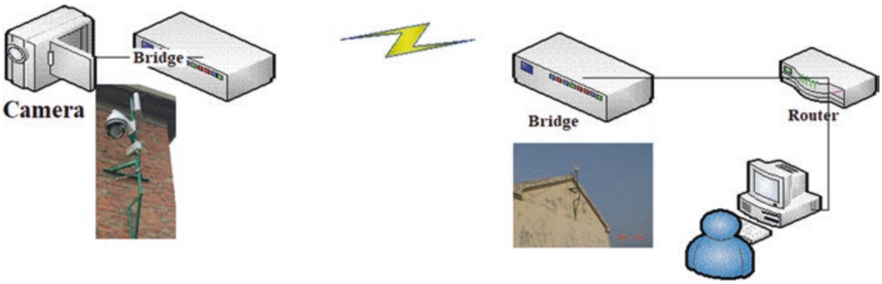


**Fig. 2.10** Network camera and wireless bridge

**Real-Time Data Monitoring**

The information management platform of "Huantai Precision Agriculture Demonstration Project" includes the several parts of field basic information management, soil moisture data collection and management, video monitoring, information announcement, etc. Among them, the basic information management module is responsible for the storage and maintenance of basic information such as soil nutrient distribution map, soil formula fertilization information, area, and facilities. The soil moisture data collection and management module is responsible for managing and analyzing the data collected by the wireless sensor network nodes in real time. And the platform displays the real-time information includes node number, data collection time, and soil moisture content. The user can choose to display all node information or only certain node information. The video monitoring module is responsible for monitoring the field environment, and the user can remotely adjust the focal length and gimbal of the webcam.

### *2.3.3 Application of IoT in Aquaculture Environmental Monitoring*

Aquaculture IoT is an important application area of agricultural IoT. To address the existed problems such as the lack of effective information monitoring technology and methods and the low level of online monitoring and control of water quality, the aquaculture environmental monitoring system (see Fig. 2.11) adopts IoT technology to achieve real-time online monitoring of water quality and environmental information, abnormal alarms, and water quality warnings. Through information transmission channels such as wireless sensor networks, mobile communication networks, and the internet, the abnormal alarms and water quality warnings were notified to the aquaculture managers. Based on water quality monitoring results, aquaculture managers adjust control measures in real time to maintain stable water quality and create a healthy water environment for aquatic products.

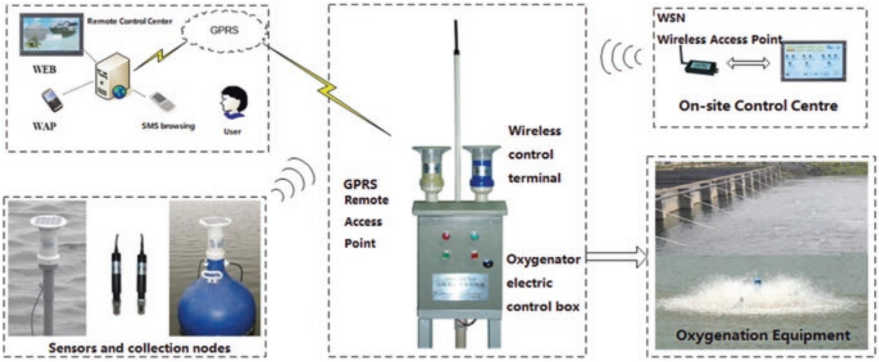


**Fig. 2.11** Aquaculture environmental monitoring system

### Intelligent Water Quality Sensors

The hardware structure block diagram of the intelligent water quality sensor consists of signal detections and conditioning module, microcontroller, TEDS spreadsheet, bus interface module, power supply, and management module. The microcontroller uses the MSP430F149 from TI, which is a 16-bit RISC structured FLASH-type microcontroller equipped with 12-bit A/D, hardware multipliers, PWM, USART, and other modules. It makes the hardware circuit of the system more integrated and miniaturized. It has a variety of low power consumption modes designed to consume between 0.1 and 400 μA at 1.8–3.6 V and 1 MHz clock conditions, making it ideal for low power consumption product development. The signal conditioning circuit and the bus interface module both use low-voltage, low-power technology, which, together with efficient energy management, enables the entire intelligent sensing system to operate reliably for long periods under battery-powered conditions.

### Wireless Oxygen Controller

The wireless dissolved oxygen controller is a key part of the oxygenation control and can drive a variety of oxygenation equipment such as impeller, waterwheel, or micro-hole aeration air compressors. The wireless measurement and control terminal can be configured as a wireless data acquisition node and a wireless control node as required. The wireless control node is the hub that connects the wireless data acquisition node to the site monitoring center. The wireless control node sends the sensed dissolved oxygen information collected by the wireless collection node to the site monitoring center through the wireless network.

The wireless control node can also receive the command requirements sent from the site monitoring center to control electric control box. The output of the electric control box can control all kinds of oxygenators below 10 kw to achieve the


**Fig. 2.12** Physical diagram of the wireless oxygenation control system. (**a**) Water quality monitoring point 1, (**b**) Water quality monitoring point 2, (**c**) Water quality control point 1, (**d**) Water quality control point 2, (**e**) Site monitoring center, (**f**) Relay node, (**g**) Video monitoring equipment

automatic control of dissolved oxygen. Figure 2.12 shows the physical diagram of the wireless oxygenation control system.

#### Wireless Monitoring Network for Aquaculture

The wireless sensor network enables 2.4 GHz short-range communication and GPRS communication, with a 3 km wireless coverage on-site. Intelligent information collection and control technology is used with automatic network routing, self-diagnosis, and intelligent energy management functions. Figure 2.13 shows a diagram of a wireless sensor network.

#### Intelligent Water Quality Control System

For the intelligent regulation of water quality, the real-time dissolved oxygen volume (RV) and real-time dissolved oxygen variation (RD) are selected as the input to the controller, and the output variable is the oxygenation time (T). Then the corresponding fuzzy control rules are selected to obtain better dynamic characteristics and static quality. It is not difficult to achieve and could meet the requirements of the system. The structure principle of the fuzzy controller is shown in Fig. 2.14.

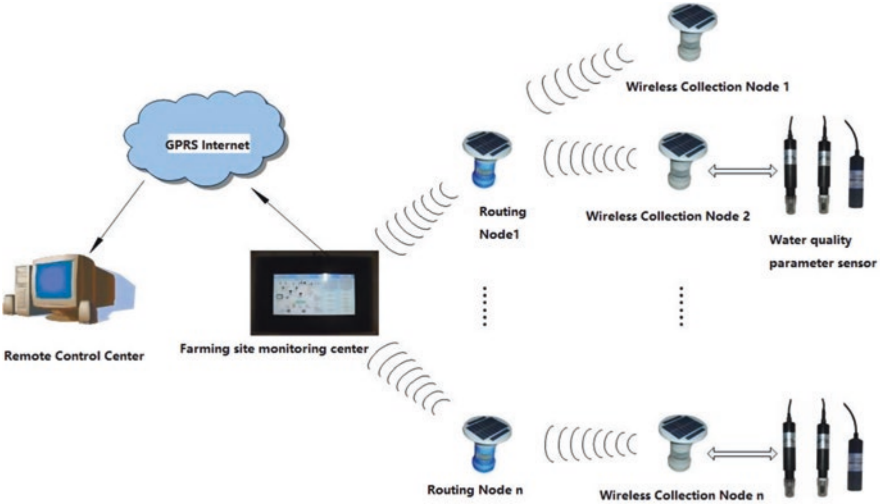


**Fig. 2.13** Wireless sensor network

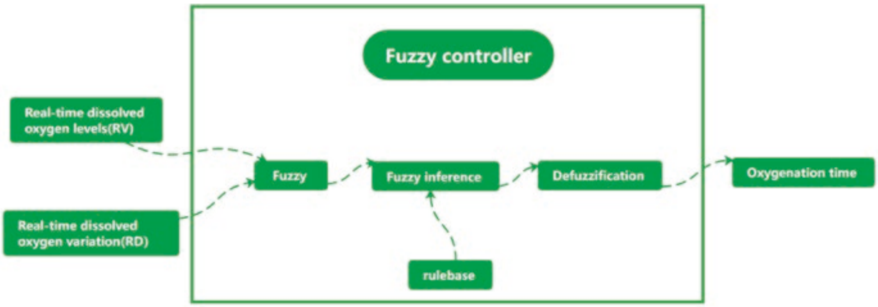


**Fig. 2.14** Schematic diagram of the structure of the fuzzy controller

### *2.3.4 Application of IoT in Agricultural Product Quality Traceability*

Aiming at providing traceability basis and means for the whole process supply chain of agricultural products circulation, taking the whole process circulation chain of agricultural products circulation as the foothold, the system comprehensively analyzes the characteristics of various circulating agricultural products and establishes a product quality and safety traceability system from procurement to retail terminal. It realizes the accurate tracking and query of product quality information of the smallest circulation unit. The functional process of agricultural product supervision and traceability system is shown in Fig. 2.15.

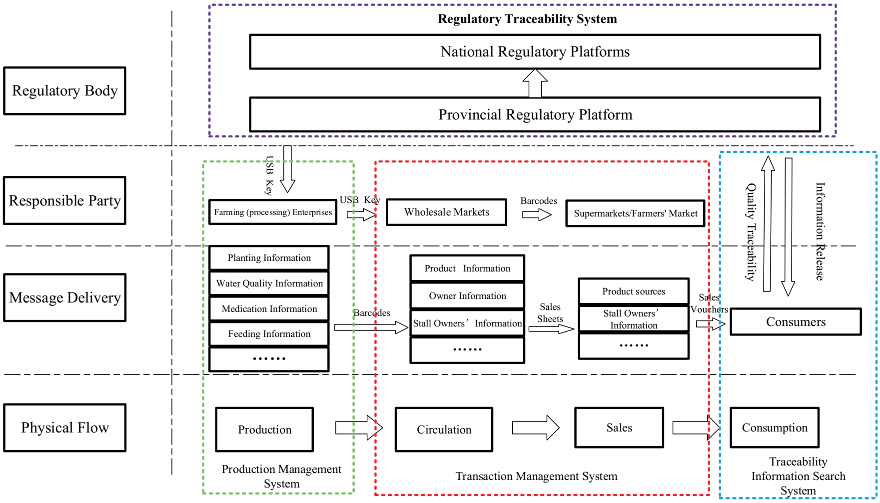


**Fig. 2.15** Agricultural products regulatory and traceability system function flow

### Production Management Systems

The production management system includes the planting and breeding quality management system and agricultural product processing quality management system developed for planting and breeding managers and processing enterprise users respectively.

Facing the internal management needs of planting and breeding enterprises and aiming at improving the management level of planting and breeding process information and the traceability of planting and breeding process, the planting and breeding quality management system analyzes the production processes of planting and breeding enterprises, such as seedling raising, stocking, feeding, disease prevention, harvesting, transportation, and packaging. The system designs functional modules such as agricultural product planting, breeding production environment, production activities, quality and safety management and sales status to meet the needs of daily management of enterprises. Based on the construction of aquatic product archives information database including basic information, production information, inventory information and sales information, the production management module, inventory management module, and sales module for different users are developed, and each module is integrated to form a safe production management system for agricultural product planting and breeding.

### Transaction Management System

Facing the needs of wholesale market management, aiming at realizing product access management and market transaction management, a practical market transaction management system is developed for different modes of wholesale markets, mainly including market access management, market stall management, and transaction management.

Market access management. According to whether the certificate of origin has bar code, the relevant breeder information and product information on the certificate are stored in the central database of the wholesale market in the form of reading or entering, so as to manage the source of products.

Market stall management carries out daily management for each stall in the market, mainly managing basic information, sampling inspection information, etc.

For the wholesale market with a high degree of informatization, according to the principle of market access, the certification of origin with bar code was required from the breeding enterprises (or wholesalers). Then the managers of the wholesale market read the bar code on the certificate of origin and store it in the central database of the wholesale market. The wholesaler downloads the relevant data on that day from the electronic scale through the wireless network, and the wholesalers print one-dimensional bar code product sales orders with manufacturer, wholesale market, wholesaler and product information when trading with customers. Once a product problem occurs, it can be traced back to the wholesaler through the relevant information of the product sales list in the wholesale market.

## Regulatory Traceability System

The regulatory traceability platform includes three functional modules: enterprise management, website management, and user management. Enterprise management includes enterprise information upload, enterprise uploading product statistics, SMS platform data statistics, and other functions. Website management includes news system, sampling announcement, enterprise profile, grand view of agricultural products, industry standards, consumer guide, database management, and other functions. At the same time, it meets the different traceability needs of government regulatory departments, enterprise users, and consumers, so as to achieve consumer's satisfaction, improve enterprise management level, and improve the quality and safety of agricultural products. Through modular design and authority division, the regulatory traceability platform can meet the regulatory and traceability needs of regulatory entities at different levels at the ministerial, provincial, municipal, and county levels. It can provide regulatory entities at all levels with detailed responsibility entities of each supply chain of agricultural products, product flow process and agricultural product quality and safety control measures of subordinate regulatory entities. In addition, the number of agricultural product traceability codes and SMS traceability numbers are statistically analyzed through the basic information platform to provide necessary technical support for competent departments at all levels to strengthen management and start risk early warning and emergency responses.

**Traceability Information Search System**

Through the research of data access general interface, the access protocol of computer network, wireless communication network, and telephone network to the same database was studied. The general API supporting SMS gateway, PSTN gateway, and IP gateway are developed. And the multi-mode query based on the central traceability information database is realized. The traceability information query system on the basis of the traceability information of each link system module takes the product label bar code and product traceability code as the query means and carries out traceability information query through a variety of traceability information query methods such as website, POS machine, SMS, and voice phone.

## 2.4 Summary

Agricultural IoT technology brings good opportunities for the development of smart agriculture. The application of IoT in smart agriculture can expand the development potential of agriculture, which is conducive to promoting the sustainable development of agriculture. IOT, together with other emerging technologies, provides reliable application technologies for the development of smart agriculture, which not only improve agricultural operation mode, but also ensure the safety and efficiency of agricultural production.

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