Design and Application of Special Sensors and Internet of Things (IoT)-based Wireless System for Agricultural Information Monitor

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Abstract. Efficient and accurate monitoring of agricultural information is the basis of implementing precision agriculture and improving agricultural productivity. In order to monitor agricultural production information comprehensively, accurately and in real time, an agricultural information monitoring system based on Internet of things (IoT) was developed, which could realize online collection and intelligent management of agricultural information. The system is composed of three layers: perception layer, network layer and application layer. The perception layer consists of various agricultural special sensors, radio-frequency identification (RFID) tag module, ultrahigh frequency RFID read/write device and other measurement modules. The network layer is composed of several ZigBee wireless communication nodes, gateway modules, coordinator modules and remote servers. The application layer includes information application system and user terminal. Sensors were developed and connected by wireless networking technology, and the sensor data was gathered and transmitted to the server terminal in real-time. Mobile terminal system was developed synchronously. The system could be applied to various agricultural scenes, such as field crops, animal husbandry, and has the characteristics of high scalability, intelligence, easy to management and use.

1. Introduction

The Internet of Things (IoT) is viewed as the third tide of the world information industry following the computer and Internet and is considered the new source of global economic growth. The IoT is a network, which ensures that sensors, radio-frequency identification (RFID), global positioning system, and information sensing devices are interconnected according to the predefined protocol and conducts information exchange and communication in a wired or wireless manner to achieve intelligent recognition, data collection, intelligent control, positioning, tracking, monitoring, and management [1-2]. In recent years, the information and communication technology represented by the Internet of things is accelerating the transformation into real productivity. From shallow level tools and products to the infrastructure and key elements of reshaping the mode of production organization, it has profoundly changed the traditional industrial form and people's lifestyle, spawned a large number of new technologies, new products and new models, and triggered the wave of global digital economy.

The innovation of IoT technology and its extensive penetration promotes the rapid development of Agricultural IoT. Agricultural IoT is the application of IoT technology in the field of agriculture. It collects the relevant information of agricultural production, agricultural product circulation and crop...
ontology by applying various sensor equipment and sensing technology, and transmits the information through wireless sensor network, mobile communication wireless network and Internet, and carries out data cleaning, processing, fusion and processing of the obtained massive agricultural information. Finally, through the intelligent operation terminal, the process monitoring, scientific decision-making and real-time service of agriculture before, during and after production are realized [3-4]. An important role of agricultural Internet of things is to automatically monitor the crops planted and promote the implementation of precision agriculture. Take dairy farming management and cow breeding as example, when cows are bred, the environmental factors of cow farms, e.g., temperature, humidity, air speed, and rainfall, have a significant effect on the growth and milk production of cows. The traditional management mode of farms collects environmental information manually and considerable manpower and input cost are needed. The traditional management mode also features low efficiency and insufficient coverage, hindering the farms from operating or being controlled efficiently. With the continuous integration of mobile internet, cloud computing, big data and other new generation of information technology, the IoT technology is accelerating the penetration of various fields in agriculture. It has been widely used in the monitoring and utilization of agricultural resources, intelligent monitoring of agricultural production, agricultural expert decision-making system, market information perception of agricultural products, quality and safety traceability of agricultural products [5-8].

Agricultural Internet of things is the reasonable results of the penetration of the new generation of information technology into the agricultural field, which will have a significant and far-reaching impact on the agricultural production and management paradigm, and will give birth to a new agricultural format: unmanned agriculture. In this work, in order to monitor agricultural information accurately in real time, an agricultural information monitoring system based on IoT was developed, which can well meet the needs of agricultural information monitoring and early warning and automatic management.

2. Design of System Framework
The IoT system was composed of three layers: perception layer, network layer and application layer [9-10]. Through this architecture, the agricultural IoT realizes the integration of "human-machine-things", which is helpful to agricultural operation and management precisely and dynamically. Figure 1 shows the structural diagram of IoT-based farm wireless monitoring system that has been developed. As shown in Figure 1, the perception layer consists of RFID tag modules, ultrahigh frequency RFID read/write devices, non-contact infrared temperature modules, agricultural information sensing modules, etc. The RFID tag modules are attached to the ears of livestock and are used to keep a dynamic record of the information of livestock. The UHF RFID read/write device reads the information recorded in the RFID tag modules and transmits the information to the gateway module via the corresponding wireless communication nodes. The noncontact infrared temperature measurement module collects the temperature data of livestock in a contactless manner and assess if the temperature is normal or not. If the temperature is normal, then the collected temperature data are sent to the gateway module via the corresponding wireless communication nodes. Otherwise, then warning information will be generated and be sent to the gateway modules via the corresponding wireless communication nodes. The information sensing module is composed of many highly integrated sensing sub-modules and corresponding wireless nodes. Various sensors are integrated into a sensing panel furnished with digital tubes, which collects the information of farms and transmits the collected data to the gateway module via the corresponding wireless communication nodes.

The network layer adopted transmission mode of combining short-distance wireless and long-distance transmission, and is composed of several ZigBee wireless communication nodes, gateway modules and coordinator modules. ZigBee is a wireless network protocol with low speed and short distance transmission. The main features are low power consumption, low cost, and can support a variety of network topologies. Based on these advantages, it is widely used in agricultural Internet of things communication transmission [11-12]. The sensing modules, infrared temperature modules, and RFID modules were connected to the gateway module by the ZigBee networking mode. The gateway
module acquires the information from the perception layer, and then transmits it to the remote server via wireless communication.

**Figure 1.** Structural diagram of IoT-based wireless monitoring system.

The gateway module is composed of the IEEE 802.15.4 wireless communication sub-module, the kernel control & processing sub-module, the heterogeneous network protocol conversion sub-module, the basic services and management sub-module, the multi-type network control & access sub-module, and the 4G (the fourth generation mobile information system) wireless network card. Among the sub-modules, the IEEE 802.15.4 wireless communication module acquires the data from sensing modules and transmits it to the kernel control & processing sub-module. The kernel control & processing sub-module is composed of the central control device and interface logic module. The interface logic module receives the data acquired by the IEEE 802.15.4 sub-module and transmits the data to the central control device for processing. The heterogeneous network protocol conversion sub-module achieves docking and integration between the wireless sensor network and all types of network protocol stacks. This sub-module processes, analyzes, integrates, and extracts multi-type information in accordance with the business and data requirements of the accessed network and service object. Then, based on the features of the data, this sub-module classifies multi-type information by business types, converts their data format, completes data frame encapsulation in accordance with the specifications and standards of the Transmission Control Protocol/Internet Protocol (TCP/IP), and accesses the remote server via the external multi-type network control and access sub-module.

By coordinating with the heterogeneous network protocol conversion sub-module and the multi-type network control and access sub-module, the basic services and management sub-module can achieve the interconnection among the multi-type heterogeneous access network, the wireless sensor network, and the business. The basic services and management sub-module implements the query and management functionalities of the sensor network data, receives the access request of remote users, identifies the users, extracts the query command information of the users from their web browsers, processes the information, and transmits the data to the remote client via the remote server. The external multi-type network control and access sub-module consists of the Time Division Synchronous Code Division Multiple Access (TD-SCDMA) coded modulation system, Internet controller and its network interface devices, and wireless local area network (WLAN) adapter device and its subsystem access devices. The external multi-type network control and access sub-module is used to access various types of networks. The 4G wireless network card module is connected to the external multi-type network control and access sub-module to transmit the data to the remote server.

The monitoring system also contains a coordinator module, which manages and controls the link between each wireless communication node and the gateway module and is used for identity management of all sensing sub-modules. The remote server acquires and manages the collected
information and data. The user terminal comprises a large screen, personal computer (PC), or mobile phone. The IoT-based wireless monitoring system could dynamically monitor the environmental, image, and video information of farms and the physical information of livestock and plants at low cost in a real-time and intelligent manner, to achieve equivalent or more profits with minimum investments and enhance the management efficiency of farms significantly.

3. Sensor Preparation and Wireless Network Construction

The perception layer is the key means for agricultural IoT to obtain agricultural information, and it is also one of the technical bottlenecks [13]. Advanced sensing instruments will be the key factor to promote the development of agricultural [14-15]. Different types of sensors were developed for various application scenarios. In order to dynamically monitor the growth of field crops online, wireless air temperature & humidity sensors, soil sensors, light radiation sensors, rainfall sensors, wind speed & direction sensors were developed. In addition, RFID wireless sensor, infrared temperature measurement device and motion sensors were developed to monitor the growth status of livestock breeding, such as dairy cattle. These sensors were connected by wireless networking technology, and the sensor data was gathered and transmitted to the server terminal in real-time. The sensing modules combine to form ZigBee wireless network via the wireless communication nodes.

3.1. Sensor Preparation

The RFID tag module is an ear tag attached to the ears of the livestock. The RFID tag module corresponds with the UHF RFID read/write device installed in the farm. The sensing distance is more than one meter. The tag keeps a record of the details of the livestock, including age, daily diet, milk yield, medical history and daily exercise. The UHF RFID read/write devices were composed of a single-chip and wireless transceiver and were installed in the farm to read the information of the RFID tag. After reading the data from the tag, the UHF RFID read/write device will transmit the data to the gateway module via the wireless communication nodes. The noncontact infrared temperature measurement module was composed of the thermopile detector chip, signal processing ASSP (Application Specific Standard Parts), alarm, LNA (low noise amplifier), 17 digit analog to digital converter and DSP (digital signal processing) unit. The infrared module collects and records the temperature of the livestock regularly every day and transmits the acquired dates to the remote server. When the temperature device detects that the temperature of the livestock are abnormal, it will transmit the warning information and the ear tag information to the gateway module via the wireless communication nodes. Then, a flicker warning will be displayed on the user terminal. The user could view the image or video of the livestock via the wireless video acquisition module.

The environmental sensing modules were composed of the temperature & humidity sensing modules, wind speed & direction sensing modules, rainfall sensing modules, soil moisture sensing modules, soil salinity sensing modules, and wireless video modules. All these modules were highly integrated into a sensing panel furnished with digital tubes. The sensors were connected to the wireless transmission nodes by means of a plug-in. CC-2530 chips were used in the wireless transmission nodes to achieve a better effect. Take the temperature & humidity sensing module as an example, the module is composed of the temperature sensor, humidity sensor, amplifier, A/D converter, check memory, CRC (cyclic redundancy check generator), SCK (CMOS clock) data cable and date triple gate. Figure 2 shows the structural diagram of the temperature sensor chip. The sensing module adopts a SHT10 chip to record the environmental temperature and humidity, and then package the data by means of the SMD (surface mounted devices) to achieve a better effect. The test temperature could range from −20 °C to 100 °C and could be measured with the precision of +0.4 °C. The measured humidity could range from 0% to 99% with the precision of ±3%. The analog signal output by the sensor will be amplified by the amplifier, and then the amplified analog signal will be converted to digital signal by the A/D converter. The check memory will secure the accuracy of A/D conversion, and the CRC generator will guarantee the safety of data communication. The SCK data cable employed to ensure the synchronous communication between the processor and SHT10 chip.
The combination of sensor chip and auxiliary module will form intelligent sensing hardware. Nanomaterials have huge specific surface area and interface, and are very sensitive to the changes of external environment. The change of temperature, light, humidity and atmosphere will cause the rapid change of ion valence state and electron output on the surface or interface, and the response is fast and the sensitivity is high. These characteristics of nanosensors will make them have considerable development prospects and huge application potential in the process of building all kinds of Internet of things. A new kind of sensor which was made by nano graphene oxide was developed. As shown in Figure 3, the sensor can accurately, non-destructively monitor the moisture information of maize leaf tissue non-destructively. Figure 4a shows the surface of active film layer. Because of the high specific surface area of nanomaterials, the sensor has high monitoring sensitivity. Figure 3b shows the sensor device was installed on the surface of leaf and monitor the crop water non-destructively. Figure 3c shows impedance response curve of the sensor after irrigation. When the moisture reaches monitoring point on the leaf, the sensor would timely and accurately monitor the change. The water transfer rate between any parts of the crop could also be calculated. By combining with wireless network transmission components, we can monitor crop moisture information online and accurately.

3.2. **Wireless Transmission Network Construction**

Coordinator, gateway and 4G mobile communication system are used to build wireless transmission network. The coordinator is responsible for communicating with the sub-nodes under its control, is used to configure the powerful MCU, and is employed for network control and management and identity management of sensor nodes, management of link state information, packet forwarding, and other tasks. Figure 4 shows the structural diagram of the coordinator, which is composed of the CC-2530 chip, support circuit, and external circuit. The CC-2530 chip and support circuit are composed of the power supply circuit, quartz crystal vibrator circuit, and reset circuit. The external circuit is composed of the serial communication module, liquid crystal display (LCD) module, and radio-frequency (RF) communication module. The serial communication module is mainly used to set communication and configuration data, whereas the LCD module is used to reflect the current real-time network status of the coordinator. The RF communication module is responsible for the wireless communication between the network coordinator and network terminal node or other network.
coordinators. The coordinator also has other functions, such as sending web beacons, establishing a network, managing network nodes, storing network node information, seeking the routing message between a pair of nodes, and receiving information constantly. The network is characterized by a balanced automatic load of all wireless nodes. The network could be organized and maintained automatically, and network connection is visible. The position for installation could also be changed randomly without the restriction by cables. The network features good extensibility, and the quantity of the acquisition terminals could be increased or decreased at will. The same network is capable of supporting hundreds of collectors and controllers. Frequency hopping and encryption authentication mechanism can guarantee the safe and reliable operation of the system.

The gateway module connects with the coordinator module wirelessly and transmits the acquired information to the remote server via 4G wireless system. The module can monitor and manage all sensor nodes in the sensor network, schedule and allocate tasks, and take responsibility for overall or individual control. The module could also interact and combine with the mobile communication network, Internet, and WLAN and has fully modular hardware architecture. The network node equipment could acquire diverse information (including sensing information and multimedia information) from the wireless sensing network via ZigBee RF and analyze the data gradually from bottom up according to the protocol hierarchy. With the help of the Internet or local area network (LAN), users could set system parameters, manage the data acquisition network, view data, make charts, export data, and complete other operations after they access the gateway via a computer. The gateway module hardware device is composed of the IEEE 802.15.4 wireless communication sub-module, kernel control and processing sub-module, heterogeneous network protocol conversion sub-module, multi-type network control and access sub-module and external storage sub-module. The IEEE 802.15.4 wireless communication module is mainly used to acquire the multi-type sensor data and information from all network nodes correctly via the protocol layer, send it to the kernel control and processing sub-module for processing, and transmit it to the designated access network. The kernel control and processing sub-module is mainly used for the overall management of the tasks in the wireless sensing network, data fusion, and information extraction. Thus, the kernel control and processing sub-module is the major scheduling device for all of the network nodes. The heterogeneous network protocol conversion sub-module is the key for gateway equipment to implement the access function and focuses on achieving the docking and integration of the wireless sensing network with the TD-SCDMA, Internet, and other network protocol stacks.

4. Monitoring System

4.1. Windows System Development
The monitoring system is an innovative platform based on the application of IoT technology in accordance with the specifications and standards, which provides data basis and services for farm monitoring and early warning. The system platform mainly includes data acquisition of crop growth
and livestock breeding, data processing and analysis, multidimensional display, and data management. The system design and developed by adopt more Java language, based on spring MVC Web framework. MongoDB and MySQL were employed for database system. Spring cloud was used to build a secure and stable micro service distributed architecture, with high concurrent data processing capability. Role-based security authentication strategy was used, which can accurately control the authorization granularity.

The software system includes network layer, data acquisition and storage layer, multimedia data management layer and application layer. Environmental and crop information were collected in data acquisition layer. The corresponding data exchange interface was developed for different types of sensor protocols, simultaneous interpreting the sensor data and storing it to the database through various communication modes. Multimedia data management layer manages data and provides services for application layer. The multimedia data management layer is composed of the remote management module, query command analysis and processing module, and sensor information analysis management module. The remote management module can be accessed by the remote user. After the user is identified, the module will extract the browser query command information of the user, send it to the query command analysis and processing module for processing, and transmit the relevant information to the remote management module and the remote client via the webserver. The application layer includes environment and crop data processing and intelligent control of farm equipment.

Figure 5 shows the system interface of information monitoring and date presentation. The system mainly relies on sensors to collect air temperature and humidity, carbon dioxide concentration, rainfall and other information for data analysis and display. The system is mainly oriented to various agricultural production environments, such as dry land, paddy field, orchard, greenhouse, farm and extreme value. Data indicators such as air temperature and humidity, soil temperature and humidity, carbon dioxide, rainfall, wind speed, etc. could be collected. By clicking the indicators, the trend chart of daily average data in the latest week can be displayed. The acquisition frequency can be set to every 10 seconds, every 1 minute, every 1 hour, every 1 day, etc. Demonstration of real-time data collection in the monitoring system is shown in Figure 6. The system also has multi-dimensional data display function, which provides different types of trend analysis charts including multi-day, multi-hour, multi-point, etc. Researchers or technicians can understand the crop growth environment in an all-round way, and all data can be saved in the cloud and can be used to view historical records. The system has rich visualization scenario display means: trend chart, bar chart, scatter chart, three-dimensional analysis chart, etc. When the crop growth environment is abnormal, the system will automatically alarm and inform the person in charge.

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**Figure 5.** Information monitoring and date presentation interface.
4.2. Mobile Application Terminal System Development
The mobile terminal system was developed synchronously. Application software design based on the Windows Mobile OS is an efficient method for application software development [16-18]. Figure 7 shows the terminal interface of data collection. Users with mobile phones can easily query the data monitored by the system anytime and anywhere. The data was transmitted in the form of JSON, XML, soap, etc. Xutils was adopted for client network framework. Multi-thread transmission and asynchronous processing mode were adopted, which can support breakpoint continuous transmission of pictures and data. The communication interface adopts the message middleware technology. On the basis of ensuring the normal operation of the system, the data was uploaded to the central management platform according to the transmission standard system, so as to achieve the ability of reporting more than one million data per day. The transmission channel was encrypted by SSL technology and transmitted by using the HTTPS protocol to prevent eavesdropping, leakage, tampering and damage on the communication line, and has the log function to monitor the transmission process. In addition, the transmission interface also meets the expansion needs according to the characteristics of the docking data transmission and docking system.

Figure 7. Mobile terminal interface of data collection.
5. Conclusions
In summary, an agricultural information monitoring system based on IoT sensors and ZigBee wireless technology was developed, which provides data basis and services for farm monitoring and early warning. The mobile terminal system was developed synchronously. Various sensors were developed and connected by wireless networking technology, and the sensor data was gathered and transmitted to the server terminal in real-time. The application of IoT sensors and information technology helps promote the traditional management mode to be converted into an information network-based precise management mode. The system allows instantaneous collection and intelligent management of agricultural information in various agricultural scenarios, such as field crops and animal husbandry. Furthermore, the system has advantages of high intelligence, low cost, easy extension and simple structure. In the future, with the progress of sensing technology and the continuous in-depth fusion of IoT and agricultural scenarios, the information monitoring efficiency will be further improved.

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