Progress and Prospect of Wireless Sensor Network Technology in Modern Agricultural Data Monitoring

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ABSTRACT

Wireless sensor networks are self-organizing network systems with wireless communication composed of a large number of micro sensor nodes, which have been widely applied in modern agriculture. This paper expounds on the progress of wireless sensor networks in modern agriculture both domestically and internationally, provides a brief explanation of the relevant technologies used, and simultaneously analyzes and prospects the current process of data monitoring in agriculture using wireless sensor networks. It is believed that wireless sensor network technology will be the development direction of modern agriculture.

KEYWORDS: WSN；Internet of Things；modern agriculture

1. Introduction

Since the 1990s, technologies such as Global Positioning System (GPS), Geographic Information System (GIS), remote sensing system, information acquisition system, and decision support system have developed rapidly. Agriculture that integrates modern information technology and agricultural science and technology has become an important agricultural model for developed countries to increase agricultural output and improve the utilization rate of agricultural resources, leading agricultural production into a new stage of development [1]. The 14th Five-Year Plan for the Development of National Agricultural and Rural Informatization mentions the need to build smart agriculture, which includes seven aspects: smart seed industry, smart farmland, smart planting, smart animal husbandry, smart fishery, smart agricultural machinery, and smart agricultural reclamation. The agriculture, which includes seven aspects: smart seed industry, smart farmland, smart planting, smart animal husbandry, smart fishery, smart agricultural machinery, and smart agricultural reclamation. The agricultural Internet of Things (IoT) has different applications in the above fields. Among them, smart farmland obtains various agricultural parameters in real time through sensors, such as climate and soil information; smart planting uses IoT technology in management to solve orchard information monitoring and product quality traceability [2].

As one of the core technologies of the IoT, wireless sensor network (WSN) technology is also widely used in modern agriculture. Due to its characteristics of self-organization, low cost, low power consumption, easy deployment, collaborative work, and strong data collection capability, it can play an important role in modern agriculture, such as greenhouse environment detection and control, precision agricultural sowing, precision irrigation and fertilization, and crop growth and environment monitoring. To develop modern agriculture, it is necessary to fully understand the progress of WSN technology in current agricultural applications.

WSN and cloud computing are key technologies in the smart agriculture system that are progressive and synergistic. WSN, as a distributed data acquisition system, consists of a large number of sensors to perceive the agricultural environment in real time. Cloud computing, on the other hand, provides high computing power, which can solve the problem of large amounts of data in modern agriculture. The two collaborate with each other: WSN provides raw data for cloud computing and processes the data. WSN technology is often at the bottom of the framework in modern agriculture and is the core technology of the perception layer.

Data collection is a key part of WSN in modern agriculture. For example, in greenhouse cultivation, it collects indoor soil temperature, humidity, light intensity, etc., and transmits these data to the data processing center for analysis to achieve monitoring of indoor data.

This paper briefly introduces the domestic and foreign research progress in this field and studies and prospects the current data monitoring process of WSN in modern agriculture.

2. Research Status at Home and Abroad

2.1 Domestic Research Status:

Wireless Sensor Networks (WSN) are network systems self-organized by a large number of low-cost, miniaturized sensor nodes through wireless communication technology, and they have now been widely applied in modern agriculture. In China, research on the relevant applications of wireless sensor networks in agriculture mainly focuses on several directions: selection of monitoring objects, stability and reliability of the system, overall cost and cost performance, transmission of monitored data, and processing of experimental data.

In the selection of monitoring objects, there are mainly two directions: monitoring plant physiological information and monitoring environmental factors. For example, in monitoring plant physiological information, a greenhouse wireless monitoring system is constructed using DSP and acoustic emission sensors, with a corresponding wireless sensor network designed [3]. In research on the stability and reliability of the system, relevant researchers have carried out hardware design for the agricultural Internet of Things monitoring system, including the design of the main control circuit, wireless communication circuit, and selection of sensors, thus establishing a reliable and stable wireless sensor network scheme [4]. Meanwhile, to solve the problems of high cost, high power consumption, and low efficiency of manual inspection in traditional agricultural Internet of Things, relevant researchers have designed an Internet of Things-based monitoring system to study environmental parameters in greenhouses. This system uses an STM32 microcontroller as the control core to collect information such as temperature and light intensity and upload it to the platform for supervision, which greatly improves management efficiency [5]. To address the issues of traditional agricultural environmental data collection and high labor intensity, domestic experimenters have designed a monitoring system for rapeseed growth data through wireless sensor networks and provided design ideas for corresponding software and hardware. This system can meet the requirements of low cost and suitability for large-scale deployment and application [6]. In the design of practical and cost-effective hardware systems for the application of wireless sensor networks in agriculture, domestic researchers have designed a lightweight wireless communication protocol stack, which can run on low-end processors, reduce requirements for communication equipment, and at the same time, through the design of relevant nodes, achieve the goal of reducing hardware costs while collecting environmental data[7][8]. In the process of data transmission, relevant experimenters have adopted a new type of narrowband Internet of Things technology to solve data transmission problems [9].

Finally, regarding the processing of experimental data, domestic researchers usually integrate the data collected from terminal nodes and regulate the experimental objects through relevant algorithms. For example, compressed sensing technology is used to make the results close to the reconstructed signal, thereby reducing communication energy consumption and the amount of transmitted information [10].

2.2 Foreign Research Status:

In modern agriculture, wireless sensor networks (WSNs) are mainly used to collect parameters related to atmospheric conditions. A WSN consists of multiple sensor nodes that monitor soil properties, such as humidity and other data. Relevant foreign research teams have utilized decision-making systems to effectively control irrigation, fertilization, and climate control systems in greenhouses through crop development models. They precisely regulate temperature and humidity levels, and adopt appropriate inputs to manage crops efficiently, thereby increasing yields [11].

Meanwhile, monitoring and control of environmental conditions are equally important. By studying the spatial, temporal, and vertical variations of the main environmental parameters in winter CSGs (controlled environment agricultural systems) and providing climatic characteristics, monitoring and control of greenhouse environmental conditions can be achieved [12].

In addition, relevant foreign researchers have pointed out that WSNs can provide a new paradigm for improving crop production and yields. They can help monitor crops in protected environments such as greenhouses. WSNs ensure that the optimal climatic conditions for crops are met by monitoring various parameters and sending them to a central repository. For effective monitoring, a Variance Adaptive Spreading (VAS) sampling technique is used to determine the perceived data. By optimizing the sampling frequency of data collection, the proposed system saves energy consumption by reducing the number of transmissions without affecting data reliability [13].

In terms of applying communication technologies to traditional agriculture, foreign scholars have developed and tested an IoT-based zone irrigation system, whose main function is to optimize plant growth conditions and reduce various consumptions. The network transmits crop growth data to a server (Raspberry Pi) through radio frequency (RF) communication. Finally, to control irrigation, a fuzzy logic controller (FLC) is used to process the data and make optimal decisions [14].

3. Concept of Agricultural Internet of Things (IoT)

The agricultural Internet of Things (IoT) is the integration of IoT technology and the agricultural industry. It involves deploying a large number of sensing devices such as environmental sensors, crop growth sensors, and livestock status sensors at agricultural production sites to collect real-time data on all elements of agricultural production. Then, through wired or wireless communication technologies such as ZigBee, LoRa, 4G/5G, and NB-IoT, the data is transmitted to cloud platforms or local control systems. Furthermore, big data analysis, artificial intelligence algorithms, and other techniques are used to process the data, explore the correlation between environmental factors and crop growth as well as livestock health, and generate decision-making suggestions such as precision irrigation, intelligent fertilization, and early warning of diseases and pests [15].

Automated control of agricultural production is realized through executive terminals such as automatic irrigation valves, unmanned aerial vehicles, and intelligent feeding equipment. At the same time, it can also provide farmers with services such as agricultural product traceability, agricultural machinery scheduling, and yield prediction, forming a complete closed loop of "perception - transmission - analysis - control - service". This promotes agriculture from the traditional experience-based production to a data-driven, precise, intelligent, and efficient model, effectively improving agricultural production efficiency, reducing resource consumption, and ensuring the quality and safety of agricultural products. It is the core technical support for the digital transformation of modern agriculture [16].

3.1 Structure of Wireless Sensor Network (WSN):

Wireless Sensor Networks (WSNs) are distributed network systems self-organized by a large number of low-cost and low-power sensor nodes through wireless communication technologies. Their structure combines the physical characteristics of hardware deployment and various logical characteristics of functional collaboration [17]. Physically, they are centered on densely distributed sensor nodes, which integrate perception modules (for collecting environmental data such as temperature, humidity, and light), processing modules (for simple data preprocessing), communication modules (for short-distance wireless transmission), and power supply modules (mostly battery-powered). Data is transmitted to sink nodes acting as network gateways through multi-hop routing, and then the sink nodes forward the aggregated data to external networks (such as the Internet) for access and control by user terminals (computers, mobile phones, etc.).

Logically, a hierarchical collaboration mode is adopted. The perception layer is responsible for converting physical signals into digital signals; the data link layer manages the access to wireless channels between nodes and short-distance transmission; the network layer optimizes multi-hop transmission paths through self-organizing routing algorithms to adapt to dynamic changes of nodes and energy-saving requirements; the transport layer ensures end-to-end data reliability; and the application layer provides data processing and application interfaces for specific scenarios (such as agricultural monitoring and environmental surveillance). As a whole, it forms a closed loop of "perception - transmission - processing - application". With the characteristics of self-organization, strong invulnerability, and wide coverage, it is widely applied in various fields requiring real-time monitoring and intelligent response [18].

3.2 Characteristics of Wireless Sensor Networks (WSNs):

The core characteristics of wireless sensor networks (WSNs) are reflected in multi-dimensional collaborative operations: Nodes are deployed in a dense and distributed manner in the monitoring area. Each node integrates a sensing module (for collecting physical quantities such as temperature, humidity, light, and vibration), a processing module (for data preprocessing such as filtering and compression), a communication module (for short-distance wireless transmission), and a battery-powered module. Data is forwarded node by node to sink nodes through a multi-hop routing mechanism, and after being aggregated by the sink nodes, it is transmitted to external networks (such as the Internet) for access by user terminals.

The network has strong self-organization and self-healing capabilities, enabling nodes to automatically discover neighbors and form a topology. When some nodes fail due to malfunctions or energy depletion, the network can dynamically adjust the routing to maintain communication [19].

4. Application of WSN in Modern Agricultural Data Monitoring

4.1 Data Collection and Hardware Design:

In modern agriculture, a wireless sensor network (WSN) usually consists of terminal nodes, router nodes, coordinator nodes, and a data processing part [20]. Among them, terminal nodes, also known as sensor nodes, are responsible for perceiving the environment and collecting data, monitoring various types of information such as temperature, humidity, and light. The design of terminal nodes generally considers the following aspects: main control module, power supply module, reset module, wireless communication module, voltage stabilization module, etc. [9][21].

Poor anti-interference ability and low precision of positioning nodes are usually difficult problems in the current agricultural application of wireless sensor networks. In this regard, relevant researchers have designed a precision agricultural WSN positioning node based on a digital frequency synthesizer [22][23]. This node uses a digital frequency synthesizer to replace the frequency synthesizer in the WSN positioning node, achieving the effect of reducing errors after simplifying the structure. Meanwhile, to solve the problems of low flexibility and high cost of traditional environmental monitoring, relevant researchers focused on the design of sensor nodes. The sensor nodes collect greenhouse environmental data, and then the gateway nodes transmit the data to the management platform through the GPRS network [8].

The coordinator gateway node is equivalent to the sink node in the sensor network. As the center of the sensor network, it is responsible for starting and maintaining the network, while aggregating the data from terminal nodes and uploading it [24][25][26].

4.2 Data Transmission and Final Processing:

The information collection of terminal nodes is a key part in wireless sensor networks. After acquiring the collected data, how to transmit it to the upper-layer server efficiently and orderly is the ultimate goal of the wireless sensor network platform. In this regard, relevant personnel have proposed a wireless sensor network application framework suitable for agricultural monitoring (WSNFFA), which divides it from the data perspective into information collection and aggregation, transmission, and management. Among them, the data receiving server is used as a link to transmit data to the upper layer [27]. In addition, some researchers have connected WSN to the IPv6 network to realize real-time greenhouse environmental data monitoring of intermediate functional modules based on the HTTP protocol [28].

In wireless sensor networks, data processing is often an important part connecting raw data and practical applications. Through data processing and optimization, it can reduce redundant data, save the deployment cost of terminal nodes, and enhance the feasibility of information. To improve the balance of network energy consumption and extend the network life cycle, some domestic research teams have improved the feasibility of the algorithm by introducing a deviation threshold into the iterative equation of the algorithm [29].

5. Conclusion

WSNs are indispensable in the development of modern agriculture. Modern agriculture is faced with many challenges such as improving production efficiency, ensuring the quality of agricultural products, and optimizing resource utilization. Through a large number of distributed sensor nodes, WSNs collect environmental data in real time and accurately, providing comprehensive and accurate data support for agricultural production, and ensuring the healthy growth of crops and the sustainable development of agriculture.

However, there are still some problems in the application of WSNs in modern agriculture, such as: sensors are difficult to cover the entire area, the overall cost is relatively high, the anti-interference ability of the system needs to be further improved, and there is a lack of complete environmental detection data, etc.

Therefore, this paper holds that, regarding the application of WSN in modern agriculture, it is necessary to build an acquisition platform through internet-related technologies, enabling managers to keep abreast of the operation status of greenhouses at any time. Meanwhile, more environmentally friendly detection technologies should be adopted, such as solar power generation technology. Finally, a crop plant information database should be established to formulate the most suitable growth decision-making environment for different growth stages of various crops, so as to promote agricultural informatization.

Agriculture in the future will rely more on wireless sensor network technology, which will promote its wide application and innovation in future agriculture, helping agriculture achieve intelligent and sustainable development.

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