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Analysis of Agricultural Internet of Things Technology and Its Application Scenario Development

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Abstract: *The traditional agricultural production model faces increasingly prominent issues such as low efficiency and poor resource utilization, leading to growing demands for industrial upgrading and quality improvement. With the advancement of modern IoT (Internet of Things) technology, the deep integration of agriculture and IoT has emerged as a new development direction. This paper focuses on agricultural IoT, analyzing its development background, application scenarios, common challenges and solutions, as well as future trends, aiming to provide insights and inspiration for the better application of agricultural IoT.*

Keywords: *Agricultural IoT; Facility Agriculture; Application Scenarios; Development Analysis*

1. Introduction

1.1 Background Analysis

With the global population remaining at a high level [1], the demand for food continues to increase [2]. Traditional agriculture faces significant challenges, with its limitations in production efficiency, resource utilization, and the quality and safety of agricultural products becoming increasingly evident. To address these issues, traditional agriculture must undergo transformation, shifting toward modernization and intelligence [3]. The rise of agricultural Internet of Things (IoT) technology has brought revolutionary opportunities to the field of agriculture. IoT technology enables real-time monitoring of crop data, achieving precise management and improving resource utilization, product quality, and yield. Moreover, with advancements in sensor and communication technologies, its application in agricultural production has become more efficient. Additionally, IoT facilitates traceability of agricultural products, ensuring quality and gaining consumer trust. The application of agricultural IoT technology effectively addresses challenges in modern agricultural development, demonstrating broad prospects and significant potential.

1.2 Overview of Agricultural IoT Technology

The Internet of Things (IoT) refers to the use of various information sensing devices (such as RFID technology, infrared sensors, global positioning systems, laser scanners, etc.) connected to the internet, forming a vast intelligent network platform capable of real-time perception, efficient transmission, and intelligent processing of information [4]. This platform enables remote intelligent control and management of various devices.

Agricultural IoT is an innovative agricultural application technology that integrates sensors, wireless communication networks, and intelligent terminal technologies into the agricultural sector, spanning the entire production process from pre-production to post-production [5]. In practical applications, sensors are widely used, including temperature and humidity sensors, light sensors, and soil pH sensors, which work simultaneously to monitor and collect ecological environmental data and crop growth physiological information in real time. Large volumes of data are transmitted via wireless communication networks, such as low-power wide-area networks like ZigBee, to intelligent terminals. These terminals employ

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advanced technologies like big data analytics and artificial intelligence algorithms to deeply analyze and process the transmitted data, providing farmers with precise and scientific decision-making support. This enables accurate and efficient management of agricultural practices such as fertilization, irrigation, and temperature regulation, reducing costs while ensuring high-quality and high-yield crop production.

2. Application Scenarios of Agricultural IoT Technology

The application scenarios and promotion prospects of agricultural IoT technology are extremely broad, with many typical and specific use cases as illustrated in Figure 1.

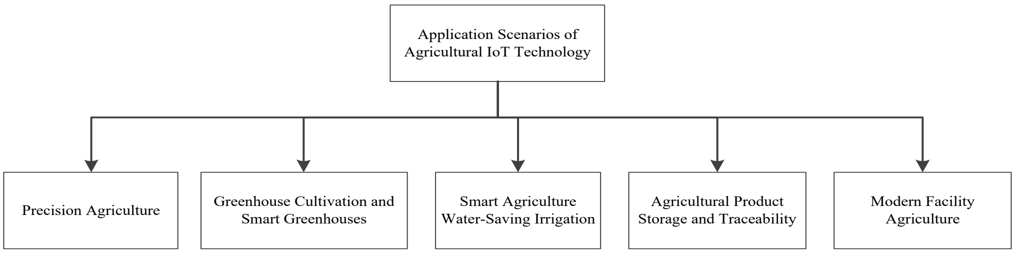

Figure 1 Typical Application Scenarios of Agricultural IoT Technology

2.1 Precision Agriculture

As a cutting-edge application of agricultural IoT technology, precision agriculture involves targeted production management based on the unique characteristics of land and plants. In this critical agricultural management model, sensors for temperature, soil moisture, weather, and other parameters collaboratively form a monitoring network. This network enables comprehensive and multi-dimensional monitoring, collecting real-time data on soil temperature, air temperature and humidity, light intensity, soil fertility, and other factors. This allows for the prediction of optimal environmental conditions for crops and timely warnings of potential pest and disease outbreaks.

By deploying temperature and humidity sensors, soil pH sensors, and light sensors in fields, farmers can assess soil and crop health in real time. For example, temperature and humidity sensors precisely measure soil moisture and ambient temperature, helping farmers optimize irrigation practices to avoid over- or under-irrigation. Soil pH sensors allow farmers to determine soil acidity or alkalinity, guiding the use of soil conditioners for optimization.

Furthermore, precision agriculture integrates big data analytics and artificial intelligence technologies. By leveraging big data platforms that aggregate soil, climate, and crop growth data, farmers gain more accurate planting decision-making support. Advanced algorithms such as machine learning and deep learning can model and predict soil conditions and crop growth, assisting farmers in planning optimal planting cycles, crop selection, and fertilization amounts. Combined with real-time data and precise control, precision farming significantly improves crop yields and resource utilization, achieving zero-pollution agriculture.

2.2 Greenhouse Cultivation and Smart Greenhouses

Smart greenhouses and greenhouse cultivation are typical applications of agricultural IoT technology, creating controlled environmental conditions for crop growth and significantly expanding the range and growth cycles of crops [6].

In greenhouse cultivation and smart greenhouses, IoT technology enables refined and intelligent temperature management. High-precision temperature and humidity sensors installed inside greenhouses detect ambient conditions and transmit data via intelligent networks to control systems. These systems can automatically activate temperature-regulating devices based on predefined thresholds. Smart greenhouses are also equipped with remote monitoring devices, allowing farmers to track and adjust temperature conditions in real time using smartphones or other information devices. For instance, if temperatures rise excessively, cooling systems such as water curtains are activated to lower the temperature through evaporative cooling. Conversely, if temperatures drop too low, heating systems are engaged. Additionally, environmental monitoring nodes are strategically placed throughout the greenhouse, enabling farmers to precisely control growth conditions, extend growth cycles, and improve crop yield and quality per unit area.

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2.3 Smart Water-Saving Irrigation in Agriculture

Smart irrigation systems, a common application of agricultural IoT technology, are particularly valuable in regions with water scarcity [7]. Traditional irrigation relies on empirical judgment, often leading to over- or under-irrigation and water waste. In contrast, IoT-based smart irrigation systems monitor soil moisture and meteorological data in real time, enabling scientific control of water usage tailored to crop growth needs, thereby reducing waste.

Smart irrigation systems rely on soil moisture sensors to monitor water levels in real time. When soil moisture falls below a set threshold, the system automatically initiates irrigation and distributes water evenly via valves, preventing uneven watering and reducing groundwater pollution caused by excessive irrigation. This approach saves labor and resources while achieving balanced agricultural irrigation.

2.4 Agricultural Product Storage and Traceability

Agricultural IoT technology is applied in storage, logistics, and production management. For example, high-sensitivity temperature sensors and intelligent monitoring devices are installed in granaries, cold chains, and transport vehicles to monitor temperature changes in real time. If temperatures deviate from preset thresholds, the system triggers alarms and automatic adjustments.

In terms of traceability[8], sensors collect data on light, weather, and pesticide use during production, which is stored and analyzed on cloud platforms. This provides producers with actionable insights to ensure healthy crop growth, while consumers can access detailed information about production and processing. Traceability platforms enhance consumer confidence in food safety, promote healthy and sustainable agricultural practices, and ensure the quality of agricultural products.

2.5 Modern Facility Agriculture

Traditional agricultural production relies on natural environmental conditions. If these conditions change drastically, they may disrupt the required parameters for crop growth. For example, excessively low temperatures in spring can hinder corn seedling development, while heavy autumn rains and insufficient sunlight may delay wheat harvesting. Consequently, the "weather-dependent" nature of traditional farming makes it vulnerable to extreme climatic conditions, potentially creating unfavorable growth environments and compromising yields.

The core objective of facility agriculture is to leverage modern technology to make crop growth conditions controllable. It focuses on providing precisely tailored environments—whether for plant growth or animal husbandry—by actively creating optimal conditions rather than relying on natural variables. This approach breaks through the limitations imposed by nature, enabling intensive and efficient agricultural production.

The advantages of facility agriculture lie in its controlled environments and intensive production methods. However, this also increases operational complexity—the more precise the environmental control, the greater the need for actuators and sensors. These components must be interconnected, forming an integrated network that combines agricultural IoT with compact facility agriculture equipment.

Facility agriculture significantly enhances precision in crop management, boosts production efficiency, and optimizes resource utilization. It also conserves land resources, laying a solid foundation for large-scale adoption. To achieve widespread implementation and mass production, facility agriculture requires a vast array of sensors and actuators. Thus, agricultural IoT serves as both a foundational prerequisite and a critical enabling technology for modern facility agriculture.

3. Challenges and Solutions in Agricultural IoT Applications

3.1 Technical Challenges

Despite rapid development, agricultural IoT technology faces several technical issues. First, sensor technology currently lacks the accuracy, stability, and reliability required for data collection in complex agricultural environments. Factors like temperature and humidity can lead to data errors. To address this, more durable and precise sensors are being developed, using high-quality waterproof and corrosion-resistant materials to ensure stable operation in harsh conditions. Additionally, sensor calibration

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technologies are improving, employing advanced algorithms and models to minimize measurement errors.

Moreover, the vast amounts of sensitive data collected by agricultural IoT systems raise security concerns. Production data, including farmer information, cultivation techniques, and yields, can cause significant losses if leaked. Blockchain technology has emerged as a solution, offering immutability and transparency. By storing data on blockchain networks, agricultural IoT systems can ensure data integrity and privacy through encryption, safeguarding information even in the event of a system breach.

3.2 Insufficient Network Coverage and Stability

Agricultural fields often span large areas with complex terrain and soil conditions, leading to weak network signals and delayed data transmission. Poor weather or communication signals can cause network failures, disrupting online monitoring systems and negatively impacting crop production.

To mitigate this, low-power wide-area network (LPWAN) technologies like NB-IoT are being adopted. These technologies provide extensive wireless coverage, ensuring reliable remote control of IoT devices even in areas with weak signals.

3.3 Farmer Adoption and Popularization

As the primary stakeholders in agriculture, farmers' acceptance and participation are crucial for IoT adoption. However, some farmers remain hesitant due to high costs. The expense of purchasing and maintaining IoT devices is prohibitive for small-scale farmers, hindering widespread adoption.

To reduce costs, manufacturers and research institutions are working to lower prices and upgrade technologies. For example, cheaper yet stable sensor technologies are being developed, and economies of scale are reducing production costs. In terms of maintenance, IoT platforms are introducing smarter solutions, such as real-time device monitoring to predict and prevent failures, minimizing manual inspections and repair costs.

4. Future Prospects and Recommendations

4.1 Future Trends in Agricultural IoT Technology

In the future, agricultural IoT will trend toward intelligence, automation, and sustainability. With the widespread adoption of 5G, high-efficiency, low-latency data exchange will enhance real-time monitoring and intelligent analytics. Artificial intelligence will play a greater role in sensor data analysis, enabling better monitoring of soil nutrients, moisture, and pests. Robotics will accelerate agricultural automation, leading to more automated farms and vehicles.

For sustainability, smart agriculture will integrate big data, blockchain, and IoT to build agricultural informatization. Precision irrigation and fertilization will improve resource efficiency, while traceability systems will enhance food safety and trust, promoting low-carbon and environmentally friendly practices.

4.2 Expansion of Applications

As IoT technology matures, its applications in agriculture will broaden. In livestock farming, temperature and humidity sensors can monitor environmental conditions, while biosensors track animal health and behavior. In granary management, sensors can detect temperature, humidity, and oxygen levels to prevent spoilage and waste.

4.3 Policy Recommendations

Government subsidies, tax incentives, and funding for advanced technology projects can encourage farmers and agribusinesses to adopt IoT. Standardizing IoT device protocols will facilitate interoperability and collaboration. Economically, agricultural IoT can boost production, reduce resource waste, create jobs, and support green agriculture.

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5. Conclusion

IoT technology is a driving force in modern agriculture, with promising applications in improving yield and food safety. By enabling precise monitoring and control of agricultural conditions, IoT enhances efficiency and product quality, supporting sustainable development. Applications in precision farming, smart greenhouses, irrigation, and traceability empower farmers to adopt scientific practices and reduce resource waste.

Although agricultural IoT faces technical, network, and adoption challenges, ongoing innovation and policy support promise a bright future. As technology advances, IoT will become more intelligent and automated, integrating with big data and AI to build a mature agricultural informatization system. Through collective efforts, agricultural IoT will contribute to global food security, improved product quality, and sustainable development.

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