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Research on Precision Agriculture Monitoring System Based on Internet of Things and Artificial Intelligence

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Abstract. with the continuous growth of the global population and the increasing severity of environmental issues, traditional agriculture is facing unprecedented challenges. Precision agriculture, as an innovative solution to address these challenges, aims to optimize agricultural resource use, improve production efficiency, and achieve sustainable development through the integration of Internet of Things (IoT) and Artificial Intelligence (AI) technologies. This paper reviews the applications of IoT and AI in precision agriculture, exploring technological advancements and practical applications in areas such as crop monitoring, pest prediction, and resource optimization. It also analyzes the research gaps and challenges in this field. The study demonstrates that IoT can provide essential support for precision agriculture through real-time data collection and transmission, while AI optimizes decision-making through intelligent algorithms, assisting farmers in achieving precise management. However, despite significant technological advancements, the deep integration of IoT and AI still faces challenges such as device compatibility, data privacy, and system integration. This paper also suggests that future research should focus on overcoming these technical bottlenecks, especially in reducing costs, improving system integration, and promoting interdisciplinary collaboration. The integration of IoT and AI will play an increasingly vital role in precision agriculture, contributing to global food security and sustainable agricultural development.

Keywords: precision agriculture, internet of things, artificial intelligence, smart irrigation, crop monitoring

1. Introduction

With the continuous growth of the global population and the increasing severity of environmental issues, traditional agriculture faces unprecedented challenges. Precision Agriculture (PA) utilizes advanced technologies to optimize resource use, increase crop yields, and reduce environmental impacts [1]. The applications of the IoT and AI in this field provide intelligent and precise solutions for agricultural production. However, despite the significant potential demonstrated by the integration of IoT and AI, their deep fusion still faces technical challenges, such as issues of data compatibility, difficulties in device integration, and how to ensure the privacy and security of agricultural data. These issues have become critical research gaps to be addressed in the future. This paper provides a review of the applications of IoT and AI in precision agriculture, focusing primarily

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on crop monitoring, pest prediction, resource optimization, and data integration. Non-smart agricultural technologies and fields unrelated to precision agriculture will not be discussed.

2. Application of the internet of things in precision agriculture

In recent years, the widespread application of IoT technology in the agricultural sector has significantly promoted the development of precision agriculture [2]. Precision agriculture aims to enhance production efficiency, promote sustainable development, and increase crop yields through efficient resource management and decision support systems [3]. As the core of precision agriculture, IoT employs sensors, wireless communication, and data processing technologies to monitor and manage the agricultural environment in real time, ensuring that crops grow under optimal conditions. By precisely controlling environmental parameters, IoT not only optimizes the efficiency of agricultural production but also drives the intelligent transformation of agriculture [4]. The main applications of IoT are focused on real-time monitoring of soil temperature and humidity, crop growth status, climate changes, and irrigation conditions [5]. By integrating extensive agricultural data into the cloud, IoT supports accurate decision-making. Data analysis and real-time feedback enable agricultural producers to precisely adjust irrigation, fertilization, and temperature and humidity, optimizing crop growth conditions [6].

In precision agriculture, the application of IoT technology is particularly important, especially in the optimization of smart irrigation systems. The Smart Subsurface Irrigation System uses a sensor network to monitor key parameters such as soil moisture, temperature, and air humidity in real time, enabling precise irrigation management based on the data [7,8]. Although this system improves irrigation efficiency, its reliance on electricity and network connectivity remains a limiting factor in remote areas. To address this, LoRaWAN technology, with its low power consumption and long-range wireless communication capabilities, has expanded the application of IoT devices in agriculture, especially in resource-scarce regions [9]. LoRaWAN devices can operate continuously, collect data, and transmit it to a central system for analysis and decision-making, ensuring stable agricultural monitoring and management. The integration of this technology not only resolves the issues of electricity and network dependence but also enhances the system's flexibility and applicability, particularly in resource-limited areas.

The application of IoT in pest and disease monitoring also demonstrates significant potential. By combining deep learning models such as Faster R-CNN and ResNet50, Balakrishnan Ramalingam et al. proposed an insect trapping monitoring system that collects insect images through IoT and automatically identifies and classifies them, solving the problem of traditional pest monitoring that relies on manual labor and is inefficient [10]. Remote monitoring and real-time detection improve monitoring accuracy and efficiency, reducing human intervention. This research shows that IoT can not only improve monitoring efficiency in precision agriculture but also provide intelligent and automated solutions for pest and disease control, with broad application prospects.

Despite the wide prospects for IoT applications in precision agriculture, several challenges remain. First, IoT systems require numerous sensor devices and wireless communication networks, and their high costs and potential for device failures pose difficulties for application. Secondly, although existing systems provide accurate environmental data, how to transform this into effective decision support remains unresolved. The integration of multi-sensor data and complex analysis has not been deeply studied. Therefore, addressing these challenges is key to the widespread application of IoT technology.

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3. Application of artificial intelligence in precision agriculture

With the continuous advancement of technology, AI has become one of the key technologies for improving agricultural production efficiency, resource utilization, and sustainability in precision agriculture. Precision agriculture optimizes management decisions through real-time data collection and analysis, with AI technologies—particularly machine learning, deep learning, and data mining—providing strong support for this optimization [11].

Crop health monitoring is one of the key aspects of precision agriculture. Traditional methods rely on manual inspections, which are inefficient and susceptible to human factors. In recent years, AI, particularly computer vision and deep learning technologies, has gradually become a research hotspot in crop health monitoring. By equipping drones with high-definition cameras to capture images and applying Convolutional Neural Networks (such as U-Net) for image processing, it is possible to effectively identify crop growth status and potential pest and disease issues [12,13]. Additionally, AI can integrate environmental data such as temperature, humidity, and soil moisture to achieve real-time monitoring of crop health, thus providing farmers with accurate management advice. For example, Chen et al. propose an AIoT-based system that integrates deep learning with environmental data analysis, enabling real-time pest and disease monitoring [15]. The research indicates that this method not only improves monitoring efficiency but also reduces pesticide usage, thereby decreasing environmental pollution. However, although the system achieves an accuracy rate of up to 90%, its reliance on high-definition images and high-quality environmental sensors means that farmers need a high level of technical familiarity, and the high cost of the equipment may present a barrier to its use on small-scale farms.

Precise fertilization is one of the core issues in precision agriculture. AI technology analyzes soil, crop health, and environmental data to provide intelligent fertilization schemes, significantly improving fertilization efficiency, reducing fertilizer use, and minimizing environmental impact [16]. For example, Radočaj et al. mentioned that modern precision fertilization systems, using remote sensing data and machine learning techniques, can automatically adjust the amount and timing of fertilizer application based on soil nutrient needs, crop growth status, and environmental changes, achieving precise control [17]. The advantage of this system lies in its ability to provide tailored fertilization schemes based on the characteristics of the soil and crops in different regions, avoiding over-fertilization and environmental pollution caused by the lack of precise data in traditional fertilization methods. However, traditional soil sampling and prediction methods still require considerable manual labor, which limits the widespread adoption of these systems in large-scale agriculture. Moreover, although remote sensing data and machine learning methods have significantly improved fertilization accuracy, how to maintain the robustness of models across different soil types and climatic conditions remains a challenge that needs to be addressed.

AI technology has also demonstrated powerful capabilities in pest and disease control [18]. By analyzing agricultural images using deep learning models, AI can effectively identify crop pests and diseases and formulate precise control measures based on pest types and distribution. Akhter et al. proposed a precision agriculture approach combining IoT and machine learning, particularly in disease prediction in apple orchards [19]. By combining sensor data with machine learning models, they were able to identify crop diseases early and make control decisions, greatly improving the accuracy of pest and disease control. Additionally, AI-based automated pesticide spraying systems can accurately apply pesticides at the early stages of pest infestation, reducing pesticide usage and minimizing the harm to both the environment and human health. However, these systems typically require substantial sensor and image data support to ensure high-precision real-time monitoring. The accuracy of the data and real-time transmission capability are critical for the effectiveness of the

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system, particularly in agricultural environments with significant variability. Maintaining the stability and accuracy of these systems remains a challenge.

Despite the significant advancements in AI in precision agriculture, several challenges persist. First, the agricultural environment is complex, and the generalization ability of AI models is weak. There is a need to enhance their adaptability to different crops and environments. Second, there are bottlenecks in data acquisition and processing, and efficiently utilizing large-scale data remains a key issue, especially concerning computing power and network bandwidth. The high cost of AI technology also limits its adoption in small-scale agriculture. The high hardware costs and technical requirements make it difficult for small farms to adopt these systems. Therefore, developing low-cost, user-friendly solutions is critical. Lastly, technological integration and data privacy protection are barriers to the widespread application of AI and IoT. Simplifying operations and increasing farmers' acceptance remain key challenges for their promotion [20].

4. Integration of IoT and AI: applications and challenges in smart agriculture

As global agriculture faces increasing resource pressures, the integration of the IoT and AI in precision agriculture has become the core of innovative solutions. Particularly in areas such as irrigation management, crop health monitoring, and pest control, the fusion of IoT and AI has led to significant optimizations in agricultural production [21]. By combining these two technologies, agricultural productivity has been enhanced, and resource utilization and sustainability have improved markedly. The following section explores the applications and challenges associated with the integration of IoT and AI.

In the field of smart irrigation systems, a study by Froiz-Míguez et al. proposed an IoT-based smart irrigation system that integrates LoRa and LoRaWAN sensor nodes to efficiently manage water resources in urban and suburban areas [22]. The system collects key data in real time, including soil temperature, humidity, and air temperature, and utilizes fog computing technology for intelligent decision-making to optimize irrigation operations. The study shows that the system optimizes irrigation scheduling using real-time monitoring data and weather forecasts, saving approximately 23% of water resources. The long-range, low-power characteristics of LoRaWAN allow the system to be effectively deployed in large-scale agricultural areas, particularly in urban environments where multiple obstacles must be overcome, demonstrating superior application potential.

In the area of smart crop monitoring, the integration of IoT and AI has also shown significant application prospects. Karar et al.proposed a hybrid deep convolutional network (MixConvNet) model for detecting Red Palm Weevil larvae in date palms [23]. The model automatically identifies the invasion of RPW larvae by analyzing the feeding sounds within the trees, achieving an accuracy of 97.38%, which is much higher than traditional manual detection methods. Compared to conventional methods, the IoT-based sound detection system not only improves monitoring efficiency but also provides real-time feedback, thereby optimizing pest management strategies.

Additionally, Shahab et al.proposed smart agricultural technologies that combine IoT and AI to achieve real-time monitoring and optimization of soil and crops [24]. By deploying soil sensors, researchers can monitor key soil parameters such as temperature, humidity, salinity, pH, and the levels of nitrogen, phosphorus, and potassium in real time. This system enhances the precision of irrigation and fertilization and uses AI algorithms to provide optimal agricultural management recommendations to farmers. The AI-driven mobile application offers decision support based on real-time data, optimizing resource usage, increasing crop yields, and improving soil health, especially for crops like rice.

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In conclusion, the integration of IoT and AI provides innovative solutions for precision agriculture, covering applications such as smart irrigation, crop health monitoring, pest detection, and soil optimization. Advancements in each technology have contributed to improving agricultural productivity. However, despite the potential demonstrated by existing research, challenges such as device compatibility, system stability, and data processing capabilities remain. Future research must overcome these technological bottlenecks to achieve broader and more efficient applications.

5. Conclusion

The integration of the IoT and AI has become one of the core technologies driving the development of precision agriculture. Through the application of technologies such as smart irrigation, crop health monitoring, pest control, and soil optimization, significant progress has been made in agricultural production in terms of efficiency, resource utilization, and sustainability. However, despite the considerable potential of existing technologies, challenges such as device compatibility, system stability, data processing capabilities, and high costs remain. These challenges limit the widespread adoption of these technologies across different scales of agriculture, especially in resource-scarce regions with inadequate infrastructure.

To address these issues, future research should focus on improving the universality and operability of the technology, reducing equipment costs, enhancing data integration and real-time processing capabilities, and refining the application of technology in large-scale agriculture. Additionally, interdisciplinary collaboration and innovation will play a key role in advancing the development of smarter agricultural systems. With continuous technological advancements, precision agriculture will play an increasingly important role in improving agricultural production efficiency, ensuring food security, and promoting environmental sustainability. Through continuous improvement, IoT and AI integration will drive the global transition to smart agriculture.

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