Trends in Smart Irrigation for Smart Agriculture

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Smart agriculture and smart irrigation play a strategic role in agricultural production: not only they provide approaches to adapt to climate change, but also they contribute in ensuring food security, optimizing efficiency and minimizing or reducing environmental impact.

Internet of Things irrigation system smart agriculture

1. Introduction

The world's population is increasing and is expected to reach 10 billion by 2050 and food security has become one of the main issues of concern to the world [1]. Simultaneously, due to the acceleration of urbanization, the land area available for agricultural cultivation is gradually decreasing [2]. Labour shortages, frequent extreme weather, and declining soil fertility have further brought tremendous obstacles to improving productivity [3]. COVID-19 and the ongoing Russia-Ukraine conflict have also significantly increased global hunger levels [4]. All of these will exacerbate risks to food security. Currently, two ways to solve food shortages are to increase arable land or use modern technology to increase productivity. The latter is the most straightforward and effective way to address the current predicament.

Agriculture is considered one of the most critical sectors that play a strategic role in ensuring food security [3]. It is directly related to human development and social stability [5]. The development of agriculture can be roughly divided into four stages: (1) Traditional agriculture (Agriculture 1.0) mainly focuses on human and animal operations. (2) Mechanized agriculture (Agriculture 2.0) converts an agricultural activity that requires days of human sweat and draft animal labor into a few hours [6]. (3) "Agriculture 3.0" was sensor-based and designed to tailor treatments and inputs to the right place and time by accounting for variability at increasingly finer scales [7][8]. (4) The fourth is "Agriculture 4.0 (smart agriculture)", which extends the "Agriculture 3.0" approach to include sensors and robotics, and also the Internet of Things (IoT), cloud computing, data analytics, and decision support systems into an integrated "smart" approach to production [9][10][11].

Modern technology represented by artificial intelligence (AI) began to be explored in agriculture in the last century. However, due to the limited technical level at that time, it brought little substantial progress [12]. After entering the 21st century, the considerable effectiveness of AI in the industrial area has given agriculture new opportunities for change [13][14]. Intelligent technology has gradually intervened in agricultural production, and promoting intelligence has become the mainstream agriculture trend [15]. Smart agriculture (SA) uses modern industrial organizational methods, management concepts and advanced technologies to develop new concepts of modern agriculture, transforming traditional agriculture characterized by “land + machinery” into modern agriculture with “equipment + information + AI” as its core [16][17]. The SA market was estimated at USD 13.8 billion in 2020 and is projected to reach USD 22 billion by 2025 at a compound annual growth rate of 9.8% [18].

2. Trends in Smart Irrigation for Smart Agriculture

Smart irrigation is a method that uses advanced information technology and automation equipment to improve agricultural irrigation systems [19]. They have similar purposes, namely improving agricultural production efficiency, reducing resource consumption, optimizing farmland management, and improving the quality of agricultural products. As other papers have already observed, there needs to be more consistency or clarity among topics from different areas of knowledge [20]. Nonetheless, there is no doubt that any innovation in agriculture is welcome, especially when making farming more efficient.

Smart agriculture’s top five research popularity are the Internet of Things, climate change, machine learning, precision agriculture, and wireless sensor networks. The top five hot spots for smart irrigation are the Internet of Things, irrigation systems, soil moisture, smart agriculture, and wireless sensor networks. In addition, the Internet of Things, climate change, machine learning, precision agriculture, wireless sensor networks, soil moisture, deep learning, artificial intelligence, irrigation systems, low cost, and neural networks are joint research focuses of both parties.

By analyzing the limitations of current research and future research directions, the results show that although smart agriculture and smart irrigation show great promise in many aspects, they still have certain limitations. (1) Construction costs are too high, making adopting these technologies economically challenging for small-scale farmers or developing countries [15]. Future research should focus on developing more cost-effective solutions that make these technologies more accessible to farmers. (2) A high technology dependence, especially in areas with poor network connectivity or unreliable power supply [21]. Future research should explore technologies such as low power consumption and convenient operation. (3) There are security risks in data and privacy [14]. This is because collecting and utilizing large amounts of data have raised concerns about security and privacy. Future research should focus on creating standards and ethical guidelines for data governance. (4) Lack of standardization of equipment, leading to compatibility issues between different systems and vendors [13].

2.1. Internet of Things

The relationship between the IoT, SA and SI is closely related. The IoT can provide necessary support and help to agriculture, making agricultural production more scientific and intelligent. The IoT can combine sensors, monitoring equipment, and actuators with cloud computing, big data, AI and other technologies, bringing many benefits to agriculture [22]. For example, it can realize automated planting, fertilizing, and watering, reduce labor costs and water consumption, and improve the quality of agricultural production.

The IoT has injected new vitality and power into traditional agriculture. Through agricultural informatization and refined management, sustainable development of agricultural production is achieved and brings more opportunities and benefits to farmers [23]. Especially for farmers in developing countries, smart agricultural can help them improve agricultural production efficiency.

The IoT also brings significant improvements and benefits to traditional irrigation. By monitoring soil moisture, meteorological conditions, crop water demand and other data in real-time, farmers can accurately control the distribution and dosage of water and fertilizer, avoiding the problem of over-irrigation or under-irrigation, thus improving the efficiency of water resource utilization [8]. In addition, the Internet of Things can also help farmers optimize the energy use of irrigation systems, automatically perform irrigation tasks, and reduce energy consumption and operating costs. The IoT also supports predictive maintenance to avoid equipment damage [6].

The IoT is a broader concept that encompasses various applications, including agriculture. It involves the integration of sensors, actuators, and communication technologies for efficient data collection and decision-making.

2.2. Climate Change

The Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (IPCC) points out that climate change has caused colossal damage and increasingly irreversible losses to terrestrial, freshwater, coastal and pelagic marine ecosystems and is affecting the world [24]. Therefore, how to actively respond to climate change is a common issue the international community faces.

According to the definition of the Food and Agriculture Organization of the United Nations, smart agriculture is a new agricultural development model that can not only maintain agricultural production capacity but also achieve carbon sequestration, emission reduction and climate change mitigation in the context of responding to global climate change [25]. Currently, some countries are accelerating agricultural scientific and technological innovation and the transformation of production methods, vigorously developing biotechnology water-saving irrigation technology, and actively exploring the development of climate-smart agriculture and achieving good results. The future research trend in SA and SI is alleviating the food crisis by responding to climate change.

While climate change affects agriculture, it is a broader environmental issue. The IoT and machine learning are tools that can be employed to mitigate and adapt to the effects of climate change in agriculture.

2.3. Machine Learning

With the assistance of machine learning, smart agriculture and smart irrigation continue to develop, improving agricultural efficiency and productivity. Machine learning is a branch of science that allows machines to learn without being explicitly programmed, which is the mechanism behind it. Machine learning has evolved alongside big data technologies and powerful computers to open new possibilities for unraveling, analyzing and understanding data-intensive processes in agricultural organizational settings [26].

Smart agriculture and smart irrigation development always take data, algorithms and computing power as the core elements. It uses algorithm innovation to effectively combine the “massive data” brought by modern information technology with the “amount of computing” supported by physical computing hardware platforms, forming information perception, quantitative decision-making, and intelligent control of agricultural production [27]. Machine learning brings a more standardized and sustainable management method to traditional agriculture and is expected to achieve tremendous success in the farming field.

Machine learning is a subset of artificial intelligence that involves the development of algorithms that can learn from data. It can be applied in various fields, including agriculture, to improve efficiency and decision-making.

2.4. Precision Agriculture

Precision agriculture is based on modern technical means, such as 3S technology (remote sensing, geographic information systems, and global navigation satellite systems), sensor technology, and the Internet of Things, to achieve precise control of the farming process, accurate monitoring of crop growth, disasters, and other aspects, and achieve precision farming, precision irrigation, specific fertilization, pesticide application, precise sowing, precise harvesting, earning the same or higher income with the minor investment [12]. Smart agriculture relies on modern technical means such as 3S technology and is deeply integrated with new technologies such as cloud computing, the Internet of Things, and mobile Internet. It is an all-around introduction of intelligent ideas and technology applications into agricultural production to achieve precision in farming operations, infrastructure intelligence, and modernization of industrial development [2].

Compared with precision agriculture, smart agriculture covers a broader scope. In a narrow sense, it includes commonly understood agricultural fields such as field agriculture, facility agriculture, safety traceability, and agricultural e-commerce; broadly, it uses information means represented by the Internet to analyze agriculture. It performs full-process information services and guidance, adopts innovative business operation models, and extends them to the agricultural economy. Developing smart agriculture can promote precision agriculture development and improve crop products.

Precision agriculture is a specific application of technology in farming, while IoT and machine learning are broader concepts that can be applied in various domains.

2.5. Wireless Sensor Network

The wireless sensor network is widely used in smart agricultural systems to manage and monitor the productivity and sustainability of agricultural yields. Wireless sensor technology plays a vital role in smart agriculture and smart irrigation, bringing significant benefits. First, farmers can use wireless sensor networks to optimize agriculture by monitoring multiple vital parameters such as soil moisture, temperature, antennas, and meteorological conditions in real time [28]. This helps improve the growth quality and yield of epidemics, reduce resource waste, and reduce reliance on chemical fertilizers and pesticides, making sustainable agriculture possible.

Secondly, wireless sensors also provide early detection and warning of pests and diseases. In addition, wireless sensor technology can be integrated with automation systems to automate agricultural production, including automatic irrigation, fertilization, agricultural machinery operations, etc., improving labor efficiency and reducing labor costs. Wireless sensor technology brings opportunities for informatization, automation and sustainable development to smart agriculture and is expected to promote more innovation and progress in the agricultural field [29].

Wireless sensor networks are a specific technology within the broader framework of the IoT. They play a crucial role in collecting data for various applications, including precision agriculture.

2.6. Irrigation System

The irrigation system is an engineered system widely used in agriculture and gardening fields to provide plant growth water. This can range from simple irrigation methods such as drip, sprinkler and subsurface irrigation to complex canals and pumping stations. Smart irrigation combines advanced sensors, data analysis, and automated control to achieve efficient, precise, and sustainable plant irrigation. Whether it is an irrigation system or a smart one, their primary purpose is to provide plants with the necessary water to support their growth and development. In contrast, smart irrigation is a modern, highly automated, data-driven irrigation system designed to improve efficiency and resource utilization [8].

An irrigation system is a specific agricultural technology, and when combined with the IoT and sensor networks, it becomes a part of precision agriculture.

2.7. Soil Moisture

The development of smart agriculture and smart irrigation has brought considerable benefits to agricultural production, among which precise control of soil humidity is one of the keys. First, for smart agriculture, soil moisture control optimizes agricultural growth [7]. Using sensor networks and data analysis, farmers can understand soil moisture levels in real-time to take timely measures, such as adjusting irrigation volume and frequency to ensure the soil in their fields is always within the closest moisture range. This improves immediate yield and quality, reduces water waste, and is conducive to realizing sustainable agriculture.

Secondly, soil moisture control in smart irrigation is crucial for water resources management. By monitoring soil moisture in real-time, the smart irrigation system can accurately calculate plants' water needs and adjust irrigation as needed, avoiding over- or under-irrigation. This saves water resources, reduces irrigation costs and helps reduce the risk of salinization. Therefore, effective control of soil moisture not only improves the water utilization efficiency of farmland but also helps maintain soil health and ecological balance, providing a foundation for the realization of sustainable agriculture.

Soil moisture is a specific parameter monitored in agriculture, and the technologies mentioned, such as the IoT and wireless sensor networks, are tools used to gather and analyze data related to soil moisture.

3. Conclusions

In terms of water resource management, smart agriculture enables more effective management of water resources. In terms of reducing greenhouse gas emissions, smart agriculture can reduce the negative impact of agriculture on climate change by optimizing production processes and reducing the use of energy and chemical fertilizers. In terms of renewable energy applications, smart agriculture can integrate renewable energy and reduce dependence on traditional energy, thereby reducing greenhouse gas emissions. In terms of food security, smart agriculture can improve efficiency, reduce production costs, and increase disaster resistance, thus promoting the development of sustainable agriculture. In short, almost every part of agriculture and irrigation, from planting to sowing and harvesting, stands to profit from the effect of smart technology.

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