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Recent Advancements in Wireless Sensor Networks for Optimising Smart Agriculture

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Abstract

Recently, Wireless Sensor Network has attracted attention because of its comparative advantages. The primary goal of WSN in smart agriculture is increased sustainability, connection, and efficiency. In this paper, we highlighted the key advantages, such as data security and communication, automation and reduced labour, improved crop monitoring, resource optimisation and energy efficiency in smart agriculture. However, it also points out several difficulties that prevent WSN from being used in smart agriculture. In an effort to address the issues facing the agricultural industry, technological advancements have been developed by researchers to improve WSNs. Furthermore, we outlined the technological advancements in a number of areas. Integration of IoT with sensors enables massive data collection and analysis where high-energy efficient protocols were considered. Multi-depth capacitive sensors offer detailed understanding of soil moisture and nutrient. Smart algorithms and climate-smart pest management are seen as the advanced approaches for pest management and control.

Keywords: *Smart Agriculture, Precision Agriculture, Wireless Sensor Network*

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Background to the Study

The integration of Information Technology and Agriculture gave birth to smart agriculture hence, promoting precision agriculture (Kumar and Ilango 2018). This is the use of digital techniques to reinvent, govern and optimise agricultural process. The main objective behind the invention of the smart agriculture is to meet up with the growing demand of food security by automating the processes (Wang 2023). The processes automated include pest control, irrigation, plant disease, soil nutrient management (Mowla et al. 2023) as the agriculture plays a crucial role in the economy of most of countries and even the economic backbone in some countries (Wang 2023).

Wireless Sensor Network (WSN) is one of the most important technologies considered in the 21st century (Mowla et al. 2023), which is the collection of wireless sensors deployed in a certain area based on the required data and subsequently transmitting the data to a centralized node to process the data as per the user requirement (Kumar and Ilango 2018). The technology has a wide range area of application ranging from military, sports, medicine, agriculture and others (Jawad et al. 2017). In the area of agriculture, wireless sensor network is considered as the enabling technology for efficient and low cost of smart agriculture (Wang 2023), which brings about its adoption in the area (Thakur et al. 2019). The technology is applied to measure some important physical parameters for farmers and transmit the information for further processes limiting the frequent visit of the farmers. Therefore, the objective of the paper is to highlight the key advantages WSN, such as data security and communication, automation and reduced labour, improved crop monitoring, resource optimisation and energy efficiency in smart agriculture. The rest of paper covers advantages of wireless sensor networks in smart agriculture in section 2; section 3 dwells on challenges of wireless sensor network in smart agriculture; in section 4 we have recent advancements of wireless sensor networks in smart agriculture; while section 5 covered conclusion part; lastly section 6 and 7 covers acknowledgement and references respectively.

Advantages of Wireless Sensor Networks in Smart Agriculture

Wireless sensor networks (WSNs) play an important role in smart agriculture, and this is because of the advantages the technology provided to the smart agriculture. There is huge improvement in efficiency, productivity and sustainability in smart agriculture due to those advantages. Research papers highlighted various advantages of wireless sensor networks in smart agriculture, including:

Enhance Crop Monitoring and Management

In agriculture, environmental parameters are vital due to their impact on crop quality and yield. These environmental parameters include soil moisture, temperature, humidity and PH level. In order to attain good quality and yield of crop, there is need for proper monitoring and management of the environmental parameters. Wireless Sensor Networks (WSNs) enable tracking of these environmental parameters by giving access to real-time data required by the farmers to help them make informed-decision (Hamouda and Elhabil 2017; Jawad et al. 2017; Thakur et al. 2019). Furthermore, it enables prompt intervention and adjustments in the farming practices (Lakshmisudha et al. 2016; Sahitya, Balaji, and Naidu 2016).

Resource Optimisation
Wireless Sensor Networks (WSNs) help in efficient use of resources based on crop's need. These resources include water, fertilizer and insecticide. The technology delivers precise data for efficient application of those resources (Hamouda and Elhabil 2017; Sanjeevi et al. 2020; Thakur et al. 2019). Additionally, the technology enables smart irrigation system which operates based on real-time data on soil moisture and weather condition, this in turns, helps in minimizing water wastage (Sanjeevi et al. 2020; Tyagi et al. 2020).

Energy Efficiency and Sustainability
Adopting smart agriculture is high energy consuming; being wireless sensor networks as its critical part. Some techniques recently were invented primarily to improve energy efficiency; this is by increasing the lifespan of the gadgets mostly used. One of the techniques is Simultaneous Wireless Information and Power Transfer (SWIPT) and in turns, support sustainable agricultural practices (Jawad et al. 2017; Lu et al. 2020). Additionally, implementing energy harvesting and power reduction methods guarantees long-term monitoring capabilities while minimizing energy consumption (Jawad et al. 2017; Lu et al. 2020).

Improved Communication and Data Security
Advanced WSN frameworks enhance communication performance, reducing network latency, packet drop ratio, and routing overheads, which are crucial for reliable data transmission in agriculture (Haseeb et al. 2020; Sanjeevi et al. 2020). Security measures in WSNs protect data from malicious attacks, ensuring the integrity and confidentiality of agricultural information (Haseeb et al. 2020).

Automation and Reduced Labour
WSNs automate various agricultural processes, reducing the need for manual labour and enabling remote monitoring and control of farming activities (Lakshmisudha et al. 2016; Sahitya et al. 2016). Automated systems can manage greenhouse conditions, triggering irrigation and cooling system based on sensor data, thus improving crop yields and resource efficiency (Hamouda and Elhabil 2017).

Integration with Advanced Technologies
WSNs integrate seamlessly with other technologies like the Internet of Things (IoTs), cloud computing, and artificial intelligence, enhancing overall efficiency and intelligence of agricultural systems (Abdollahi et al. 2021; Sanjeevi et al. 2020; Tyagi et al. 2020). These integrations support applications such as intelligent irrigation, smart crop monitoring, and resource allocation which further advance smart agriculture (Sanjeevi et al. 2020; Tyagi et al. 2020).

Challenges of Wireless Sensor Network in Smart Agriculture
Wireless Sensor Networks (WSNs) provides various advantages to the smart agriculture. These advantages include improved crop monitoring and management, resource optimization, energy efficiency and sustainability, improved communication and data

security, automation and reduced labour, integration with cutting-edge technologies. They improve the overall efficiency, sustainability and productivity in smart agriculture. Despite these numerous advantages, the technology still suffers from challenges which slower its widespread adoption. Researchers identified those challenges as:

Path Loss and Signal Degradation

Dense vegetation and taller trees lead to significant path loss in wireless communication systems. This loss mainly happens because the leaves, branches, and trunks serve as obstacles, adding extra layers of interaction that diminish radio signals as they move through the environment. The followings are number of ways factors affect signal transmission (Abdollahi et al. 2021):

1. **Absorption**: When radio waves hit vegetation, some of the energy is absorbed by the water in the leaves, branches, and tree trunks. The water molecules in the plants take in a portion of the electromagnetic energy, particularly at higher frequencies, and convert it into heat. This absorption reduces the signal strength and increases path loss, as more energy is lost within the vegetation.
2. **Scattering**: Thick leaves and branches make the signal to scatter in other directions than the straight path from the transmitter to the receiver. This scattering interferes with the straight purposely built path of the signal and the tendency leads to divergence which in turn decreases the signal strength to the desired recipient. The signals may also arrive at the receiver at different times, which results to multipath interference that distorts the link quality.
3. **Attenuation**: Attenuation through foliage is a significant factor in path loss, referring to the overall decrease in signal power as it moves through dense vegetation. The height of trees exacerbates this attenuation, as taller trees increase the amount of vegetation the signal must pass through, intensifying the effects of absorption and scattering. As a result, attenuation becomes more pronounced with greater vegetation density and height.

The combined effects of absorption, scattering, and attenuation cause reduction in strength in the received signal, commonly known as path loss. This leads to poorer quality of communication link, as weaker signals may struggle to overcome background noise, resulting in potential communication failures, lower data throughput, and an overall decline in network performance in forest or densely vegetated areas.

Energy Efficiency and Power Management

Wireless Sensor Networks (WSNs) in smart agriculture enable crop monitoring and management by providing real-time data of environmental parameters. These parameters include temperature, humidity, soil moisture and PH level. Sensors are primarily handling the task of data collection, and they are remotely placed in diverse locations with limited battery life and few options for recharging. To ensure long-term, continuous operation, it is necessary to provide efficient power management and energy harvesting techniques (Haseeb et al. 2020; Jawad et al. 2019). Here is a detailed look at these challenges and the possible solutions:

High Energy Demand in Remote Environments

Frequent data collection and transmission: In Wireless Sensor Networks (WSNs), sensors are meant primarily to continuously monitor the environmental condition and transmit data to the central hub or cloud platforms for further processes. This process is facilitated through radio communication and consumes high energy, especially where the transmission is over a long range.

Remote Deployment: In agricultural settings, sensors are usually deployed in diverse locations so as to capture the required data across the entire field. This mode of deployment, makes it difficult to change the batteries or recharge them. Moreover, it makes the sensors to work independently over a long period of time with and likely with minimal maintenance.

Efficient Power Management Techniques

Duty Cycling: This is one of the techniques for power management, where sensors operate in two modes. These modes are active and sleep mode. The sensors are periodically in active mode only during data gathering and transmission, while they are at sleep mode at the other time. This technique helps in reducing power consumption and is applied especially when constant monitoring is not required.

Data Compression and Aggregation: This is a technique where data is compressed and aggregated in the sensor node before transmission. Compression minimizes the data volume and aggregation filters the data to ensure only essential data is transmitted. This facilitates transmission and reduces the power consumption of the sensors in the process of the data transmission.

Adaptive Transmission Power Control: Adjusting transmission power based on the distance of the receiver helps conserve energy. Nodes closer to the receiver can use low power levels for transmission, saving energy while maintaining network performance.

Energy Harvesting Techniques

Solar Energy: Solar panels are frequently utilized to recharge batteries in agricultural wireless sensor networks. As numerous agricultural activities occur outdoors, sunlight is easily accessible, which makes solar energy a favorable option. Sensors powered by solar energy can function continuously, using battery storage to function at night or on cloudy days.

Wind and Kinetic Energy Harvesting: In regions with steady wind or where machinery operates often, small wind turbines or kinetic energy collectors can offer additional energy. These techniques are especially advantageous in farming environments where wind frequently blows, or where machinery and livestock can produce valuable kinetic energy.

Soil-Based Microbial Fuel Cells: In this technique, small amount of energy is obtained from the activity of soil microbes based on natural biological process occur in soil. Although, the energy is small, but can support low-powered sensors in remote areas.

Network Design and Protocol Optimisation

Energy Efficient Routing Protocols: Enhancing routing protocols for energy conservation decreases the total energy consumed throughout the network. In agriculture, where nodes might be distributed across vast spaces, multi-hop routing (where data is relayed through intermediate nodes) can conserve energy by minimizing the necessity for long-distance transmissions.

Cluster-Based Communication: In this method, nodes are organized in clusters, and each cluster has a head and members. The heads of each cluster are responsible for gathering the data from the cluster members and transmitting the data to the central hub, relieving the cluster members from the data transmission process. This facilitates efficient power allocation and extends the lifespan of the network.

Moreover, there is need for a sustainable energy sources and power-saving techniques to address the challenges of power consumption in agricultural wireless sensor networks. Effective power management and energy harvesting techniques should be incorporated into the network to deliver reliable and long-term environmental monitoring without the need of frequent maintenance. This approach will essentially support smart agriculture and improve the crop quality and yield.

Data Security and Privacy

Wireless Sensor Networks (WSNs) in agricultural practices require secure means for data transmission. This is due to the crucial role played by data in the success of agriculture. The data need to be secured from malicious attack, which could lead to intrusion or even disruption. In wireless sensor networks, sensors continuously monitor environmental factors such as temperature, humidity, PH level and soil moisture and any form of interrupt may lead to serious challenge. For instance, if an attacker intrudes into any sensor data, and provides wrong information to the farmer, it could lead to wrong decision which may cause over watering or under fertilization and it will result poor quality and yield of the crop. Moreover, unauthorized access could lead to leakage of sensitive data unauthorized parties or competitors, resulting economic challenges. To address these issues, there is need for implementation of up-to-date and strong authentication and encryption techniques to ensure well secured data transmission between sensors and the central systems. Agricultural data need to be highly confidential, accurate and ultimately protected to enhance reliability and productivity of smart agricultural practices (Haseeb et al. 2020).

Network Synchronization

Coordinating a network of agricultural sensors to ensure accurate measurements is essential for reliable data collection. This synchronization enables precise analysis of environmental conditions over time and across different locations. When sensors measure parameters like temperature, humidity, and soil moisture in sync, it allows for meaningful comparisons and a solid foundation for understanding field conditions, which aids in making informed decisions. However, achieving this synchronization can be difficult due to various environmental factors. Issues such as signal interference from plants, changing weather conditions, or geographical barriers can disrupt data transmission and lead to timing discrepancies. Furthermore, delays in network transmission, whether from these factors or limited bandwidth in remote areas, can create lags that misalign data timestamps, complicating the merging of data streams. To address these challenges, advanced synchronization techniques, such as timestamp correction algorithms and regular clock adjustments throughout the network, are essential. However, these methods require careful planning and can increase the computational and power demands on the system (Zervopoulos et al. 2020).

Scalability and Deployment

The use of Wireless Sensor Networks (WSNs) in large and heterogeneous agricultural fields comes with scalability issues since WSNs must accommodate an increasing number of sensor nodes distributed over different terrain types and heterogeneous large fields without compromising on the quality of performance. Larger agricultural fields well may experience differences in the physical conditions of soils, heights of field, and crop densities; these require flexible network topologies to accommodate very complex node densities. This scalability problem is worse based on the fact that the nodes have to be connected and data must be transmitted and relayed over long distances; single hop communication may not suffice, and creates problems of congestion. Due to these factors, WSNs in agriculture need to have a Multi-Hop or Hierarchical structure so that the data from the nodes are routed through intermediate nodes that do not need high transmission power and covers long distance. Furthermore, in optimizing these architectures for execution in agricultural environments that are possibly volatile, the architectures require self-organising protocols to enable them handle issues such as node death, battery depletion or changes in the topology without requiring human interventional input. Such robust and flexible architectures are essential for maintaining reliable, cost-effective, and energy-efficient monitoring at scale, enabling WSNs to support precision agriculture and improve farm management practices effectively (Ojha, Misra, and Raghuwanshi 2015; Rajasekaran and Anandamurugan 2019).

Environmental Impact on Communication

These environmental factors such as weather changes and type of soil have direct influence on the performance of WSNs in agriculturally-based scenarios and more often, the communication protocols have contingency measures while the sensors must be made robust to support the varying agricultural conditions and environmental stresses. For example, rain or high humidity affects the wireless signal ability of propagation or experience high path loss and communication interruption, dynamic temperature range can affect battery drainage or even harm the electronics circuits. Another factor is the type of soil because energy is damped differently in clay or in wet soil, which reduces the strength of the underground sensors signals, or with different attenuation in sand. To mitigate these challenges, adaptive communication protocols are essential: They can modify the transmission power associated with a link in response to prevailing conditions or even change the communication path in order to continue communicating. Furthermore, many sensors use resilient hardware designs and are enclosed in an environmentally protected casing, which is both water and temperature-resistant and low power consumption in different contexts prolongs battery life. These adaptive measures are important to maintain the risk free and long life of the network in the dynamic environment normally observed in the agricultural fields and to monitor the environment and keep the data precisely (Ayaz et al. 2019; Shafi et al. 2019).

Integration with Traditional Practices

The introduction of Wireless Sensor Networks (WSNs) and IoT technologies into conventional farming techniques creates considerable difficulties since they entail new competencies, courses, and adaptation to heavily procedural work. Another challenge is when farmers practiced traditional practices and when exposed to sensors or other computer technology, they are likely to resist the new technology or even misuse it. The installation, maintenance, and troubleshooting of WSN and IoT systems involve technical expertise that may be unfamiliar to many farmers, necessitating comprehensive training programs to ensure proper usage. In addition, changing their farming strategies from an experience-based orientation to a data-centred orientation involves a major cultural change. In addition, incorporating of these technologies may upset the normal work schedule because farmers must be trained on how to view real time data and also interpret trends and apply insights from a forecast model in farming. Agronomists, extension services or tech-providers should assist in providing effective instruction, interfaces and continuous technical back up so farmers can benefit from the new technologies, the conceptual knowledge being an addition to their previous knowledge to improve efficiency of the farming process and its sustainability (Ayaz et al. 2019).

Cost and Resource Constraints

The high cost of sensors affects the widespread adoption of Wireless Sensor Networks (WSNs) and other technologies in agriculture. Additionally, sensors suffer from limited processing power, high-energy consumption and low memory capabilities. Advanced sensors with adequate functionalities such as monitoring of temperature, soil moisture, humidity, PH level and crop health are expensive most especially, for small and medium-sized farms with low budget. Additionally, most of agricultural sensors are built with energy efficiency, leading them to limited processing and memory capabilities. The restricted energy availability further means that many sensors rely on intermittent duty-cycling, remaining in sleep mode for extended periods and only waking briefly to collect and transmit data, potentially affecting data continuity and real-time monitoring. These hardware limitations also hinder the use of advanced data analytics or artificial intelligence (AI) applications directly on the sensor nodes, requiring more energy-intensive data to be relayed to central processing units, which may not be feasible over long distances in rural areas. These challenges brings about obstacles to attaining affordable and energy-efficient sensors to make smart agriculture feasible for diverse farming operations (Khujamatov and Toshtemirov 2020; Mekonnen et al. 2019).

Recent Advancements of Wireless Sensor Networks in Smart Agriculture

There is a significant shift recently in agricultural industry, largely due to the resent technologies adopted. These technologies include Wireless Sensor Networks (WSNs) which is very essential to the feasibility of smart agriculture. It enables farmers collect data and analyze the data, boosting the overall farming practices and productivity (Kumar and Choudhury 2022). Wireless sensor networks is equipped with various sensors which primarily and continuously gather real-time data on key environmental factors which are vital to the crop growth and yield across diverse location within the agricultural field (Shafi et al. 2019).

Internet of Things (IoT) and Artificial Intelligence (AI) have greatly complimented the implementation of wireless sensor network in smart agriculture. This is being possible by incorporating internet of things devices which allow data collection from extensive areas over time frames. IoT sensors provide essential information about environmental parameters which are vital for determining the best condition for crop growth and yield (Rajasekaran and Anandamurugan 2019). Additionally, combining AI and machine learning algorithms with these sensor networks allows for the creation of sophisticated decision support systems that can analyze the data collected and provide farmers with practical insights to aid their decision-making. In this paper, notable aspects of wireless sensor network in smart agriculture are highlighted and discussed which gave outstanding opportunities for further adoption of the technology.

Integration of WSN with IoT

The agricultural sector has witnessed a greater transformation with the invention of Internet of Things and Wireless Sensor Networks (Dagar, Som, and Khatri 2018). These technological advancements enable the farmers to optimise their farming operations, improve crop yields, and improve overall efficiency in the farming process. The integration of IoT and WSN in smart agriculture has revolutionized the way farmers approach modern mode of farming, providing a wider range of benefits such as precision farming, real-time monitoring, automated irrigation and pest control.

One of the key advantages of integrating IoT and WSN in smart agriculture is the ability to collect and analyse vast amounts of data from various sensors deployed throughout the agricultural field (Dagar et al. 2018; Rajasekaran and Anandamurugan 2019; Rizwanullah et al. 2023). These sensors can monitor a multitude of environmental factors, such as soil moisture, temperature, humidity, and nutrient levels, providing farmers with an overall understanding of their crop's need.

Advancements highlighted by research papers because of integration of WSN with IoT include:

i. Energy Optimisation: One of the main obstacles in WSNs is energy consumption and energy utilization as most of the nodes are energy-restricted, especially due to the limited battery power. To this end, several methods such as hybrid routing algorithms have been endeavored to increase energy consciousness and to provide efficient routing circuits so that connectivity does not break in IoT assisted ad-hoc networks (Said et al. 2022).
ii. Security Protocols: However, with the use of WSNs and IoT, energy security of data has become important especially considering any external attack. New approaches are emerging for secure data transfer and accumulation especially to preserve health-related data (Preethi and Nair 2023).
iii. Cluster Head Selection: Research is consequently seeing higher preference seeking

multi-objective algorithms in relation to the choice of cluster heads. These approaches aim at optimally choosing the nodes that will act as cluster heads as a way of enhancing the network's lifetime and functionality by enhancing how data from the network is managed while at the same time conserving as much energy as possible (Altowaijri 2022).

iv. Next-Hop Selection: The ability to make a good choice of the next hop in multi-hop routing is highly important to provide low latency and high throughput in the IoT-enabled WSNs. More research is being conducted in efforts to develop techniques to create adaptive algorithms in respect to the adaptive nature of the network (Purnama, Rahman, and Fauzi 2024).

These advancements highlight the growing synergy between WSNs and IoT, making them essential for real-time applications not only in Smart Agriculture but also across various domains.

Energy Efficiency of WSN in SA

Recent research on improving energy efficiency in Wireless Sensor Networks (WSNs) for smart agriculture has led to several innovative strategies, including modifications to the LEACH protocol that significantly enhance energy efficiency. This adaptation emphasizes dynamic clustering and effective data transmission, which helps extend the network's lifespan in agricultural applications (John, Sarkar, and Davis 2024). However, when considering energy optimization, a comparative study of recent energy-efficient protocols specifically designed for smart agriculture reveals various strategies that can be employed to improve energy management, which is crucial for sustainable agricultural practices (Coboi et al. 2023). Other studies have examined different communication protocols tailored for WSNs. For example, energy-efficient methods like Zigbee have been implemented to reduce power consumption while ensuring strong connectivity among sensor nodes (Afridi, Mukhopadhyay, and Vitoria 2023). Additionally, advancements in WSNs for smart agriculture have introduced machine learning algorithms to monitor and predict energy consumption in IoT nodes within agricultural environments. These algorithms facilitate better resource management, ensuring that energy usage is optimized based on real-time data (Coboi et al. 2023). These advancements emphasize the critical need for energy-efficient solutions in WSNs, ultimately leading to more sustainable agricultural practices.

Sensing Technologies in WSN in SA

The advancement of sensing technologies in Wireless Sensor Networks (WSNs) has greatly improved monitoring, data collection and decision-making processes in smart agriculture. Gaining in-depth insights on soil moisture and nutrients levels as well as overall environmental monitoring is with the aid of recent advanced sensors such as multi-depth capacitive soil sensors. These sensors essentially optimize irrigation and fertilization practices which in turns, support sustainable farming (Bhatia, Jaffery, and Mehfuz 2023). The integration of IoT has led to the development of advanced monitoring systems which allow real data analysis and enable farmers to make informed decisions on crop management and resource allocation (Rahu et al. 2022).

Various smart sensors are being deployed to monitor different agricultural parameters including temperature, humidity and pest detection. These technologies facilitate automation and efficiency of agricultural practices as well as lowering labour cost (Shaikh et al. 2022). Moreover, the integration of robotics with WSNs has resulted in automated systems for crop monitoring and management. This technology enables precise resource application, significantly boosting yield while minimizing waste (Lima et al. 2020). These advancements highlight the transformative potential of WSNs and advanced sensing technologies in optimising agricultural practices and fostering sustainability.

Pest Management and Control

The world of modern agriculture is fast evolving and it is as a result of the growth of global population and the raising challenges of climate change. This has made it essential to integrate innovative technological solutions to tackle today's difficult challenges faced by farmers. Among aspects that received considerable focus is the aspect of management of insect pest, which has a greater impact on the overall crop yield and the agricultural productivity (Gomathi et al. 2024).

To enhance pest detection, monitoring, and control, smart algorithms for pest management in agriculture have been introduced. Machine learning algorithms are being increasingly utilized for pest detection and classification. For instance, a study presented an AI-driven interactive agriculture system that offers real-time support in pest identification and management, using deep learning to analyze soil conditions and pest populations (Kargar et al. 2022). These smart algorithms play a crucial role in Integrated Pest Management (IPM) strategies, which aimed at reducing the pest populations and as well minimizing the environmental impact. A new resource-efficient insect monitoring system that employs machine vision and edge AI has been developed to facilitate effective pest management which allows the farmers to make informed decision based on real-time data (Bouri, Arslan, and Şahin 2023).

The incorporation of climate-smart pest management practices through smart algorithms addresses the challenges brought on by climate change. These methods utilize data analytics to refine pest management strategies, adapting to shifting environmental conditions and pest behaviors (Zare, Pflanz, and Schirrmann 2022). Advanced monitoring systems, such as those that use deep learning for insect population tracking, enable high-resolution data collection. This technology supports timely interventions and precise application of pest control measures (Liu et al. 2023). These advancements highlight the potential of smart algorithms in revolutionizing pest management practices, making them more efficient and environmentally friendly.

Network Configuration and Robustness

Configuration and robustness of Wireless Sensor Networks (WSNs) in smart agriculture got advanced recently, which was made mainly to enhance its connectivity, reliability and adaptability. The incorporation of information technologies with precision agriculture has led to great milestone in some areas, such as optimized production efficiency, enhanced crop quality, reduced environmental impact and lowered resource consumption (Sun et al. 2023).

However, challenges hinder the extensive adoption of precision agriculture, including high cost of equipment, complex operation and maintenance and absence of standardized sensor network protocols. In order to mitigate these issues, researchers are investigating various technologies, which include innovative connectivity restoration scheme that ensure uninterrupted operation in WSNs. These methods tackle challenges posed by environmental factors and node failures, thereby improving the network's robustness during agricultural monitoring (Sun et al. 2023).

Disruptions in the network usually lead to downtime in prompting the introduction of collaborative data collection. The integration of Unmanned Aerial Vehicles (UAVs) with WSNs has been investigated for this issue. A bi-objective optimization scheme has been developed to enhance data retrieval efficiency and expand the coverage area, to make the network more resilient to disruptions (Balatsouras et al. 2023). Regarding configuration, advanced algorithms have been created for dynamic network reconfiguration, enabling WSNs to adapt to changing conditions in agricultural settings. These algorithms facilitate efficient resource allocation and ensure that the network remains functional despite external challenges (Mosin 2018). Additionally, implementing multi-layered network architectures can bolster robustness by distributing data processing and minimizing single points of failure, ultimately improving the overall performance and reliability of WSNs in smart agriculture applications. These advancements underscore the importance of robust network configurations in ensuring the effective functioning of WSNs in smart agriculture.

Communication Protocol of Wireless Sensor Networks in Smart Agriculture

Wireless Sensor Networks (WSNs) and Internet of Things (IoT) have brought about the development of smart agriculture. IoT provides opportunity for real-time monitoring and automation, which are crucial to attaining productivity and sustainability in farming. Various wireless protocols such as ZigBee, WiFi, SigFox, and LoRaWAN, are frequently used in smart agriculture in carrying out functions, such as irrigation, soil moisture monitoring and pest control (Mowla et al. 2023; Rahu et al. 2022). LoRaWAN and SigFox are exceptional for their energy efficiency and long-range communication capabilities, which make them ideal for most IOT applications in agriculture (Mekki et al. 2019; Rahu et al. 2022; Sangar, Biradavolu, and Krishnaswamy 2022).

SigFox and LoRa are recognized due to their battery life, capacity, and cost, while NB-IoT possesses improved latency and service quality (Sangar et al. 2022). Bluetooth Low Energy (BLE) and zigbee are appropriately for short-range communication but with a limitation in range compared to LoRa and SigFox [(Mekki et al. 2019). However, LoRa, SigFox and NB-IoT suffer from challenges of scalability and spectral efficiency due to their narrow-band communication. Innovative approaches like WiChronos and LEACH protocol are being developed to mitigate these challenges by improving energy efficiency as well as scalability.

Conclusion

The main aim of this paper is to highlight the recent advancements in Wireless Sensor Networks (WSNs) for smart agriculture focus on enhancing efficiency, connectivity, and sustainability. The technology suffers from challenges after its invention, and that affect the effective deployment and adoption of the technology in smart agriculture. Today, various advanced technologies are available to mitigate those challenges. These advanced technologies have enabled farmers to optimise their operations, improve crop yields, and enhance overall efficiency in the farming process. In this work, we focus on the recent advancements in the most critical aspects, which are Integration of WSN with IoT, sensing technologies, energy efficiency, management and control of pest, communication protocol, network configuration and robustness. These advancements illustrate a significant shift towards more intelligent and sustainable agricultural practices throughout the effective use of WSNs.

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