Smart Agriculture: A Review of Transformative Potential of IOT-Enabled Precision Agriculture and Integration with WSN

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ABSTRACT:
The world's growing population and environmental challenges necessitate innovative solutions in agriculture, making the integration of Wireless Sensor Networks (WSN) and Internet of Things (IoT) technologies pivotal. This paper explores the transformative potential of IoT-enabled precision agriculture, & the adoption of WSNs, UAVs, and IoT devices. It reviews literature addressing sensor deployment, energy optimization, and the strategic placement of nodes. The study also includes the application of these technologies in Bangladesh's agriculture, where IoT gadgets empower farmers with real-time data for informed decision-making, addressing issues of water management and soil conditions. Finally, it discusses the benefits and barriers of these innovative tactics, outlining research gaps and pertinent questions related to IoT solutions that are being implemented.

Keywords: Precision agriculture, Wireless Sensor Networks, Internet of Things, sensor deployment, energy optimization, sustainable agriculture.

INTRODUCTION:
The predicted (Global Issues - Population) global population of 9.7 billion by 2050, combined with the growing problems of climate change and pollution, imposes tremendous pressure on the world's agricultural sector. Notably, crop irrigation now consumes around seventy percent of the world's freshwater resources, and this need is expected to grow in parallel with population expansion and increasing food demands (Khriji et al. 2021). To address these global challenges, it has become critical to incorporate innovative methods and cutting-edge technologies into the farming sector, with a particular focus on the Internet of Things (IoT). Precision agriculture and (Obaideen et al. 2022) IoT-enabled technologies have emerged as pivotal tools in this process. The incorporation of Wireless Sensor Networks into precision farming aids in the collection and analysis of large datasets. These datasets (Cambra et al. 2018) unveil significant geographical variations in crucial factors like moisture and temperature. The diversity additionally allows for large-scale agricultural growth and ensures that consumers' specific quality demands are fulfilled.
Furthermore, it provides producers with the necessary instruments for continuous monitoring and management of climatic conditions in enclosed places such as greenhouses. Additionally, wireless sensor network provides (Patil and Kale 2016) effective surveillance and management strategies to combat pests and infestations that can adversely affect crop health and yield. According to (Rejeb et al. 2022),

Unmanned Aerial Vehicles (also known as drones) and the IoT have transformed the acquisition and application of agricultural information, bringing about a new age in precision agriculture. Many aspects of managing a farm, such as farm inspection and livestock monitoring, make substantial use of this technology. For example, crop yield evaluation and its height monitoring, weed mapping, and biomass monitoring have all been made more accessible through multispectral sensors (Delavarpour et al. 2021) in UAVs. Precision farming systems' possibilities are greatly improved by this combination, thereby making it possible to collect airborne data with time and space resolution. Due to the aerial data collected by UAVs and the IoT network (Obaideen et al. 2022) connecting the sensors placed on the ground, producers can see their farming operations in detail. These technological developments give farmers access to real-time information that makes it easier to make wise decisions.

LITERATURE REVIEW:

BACKGROUND:

The adoption of IoT technology in agriculture, as emphasized by (Rathinam et al. 2019), necessitates the strategic placement of a network of sensors throughout the farm. These sensors can be embedded in the soil, integrated into irrigation systems, attached to livestock, or even incorporated into weather stations. They work continuously, collecting data and wirelessly transmitting it to a central hub, typically cloud-based, where it undergoes processing and analysis.

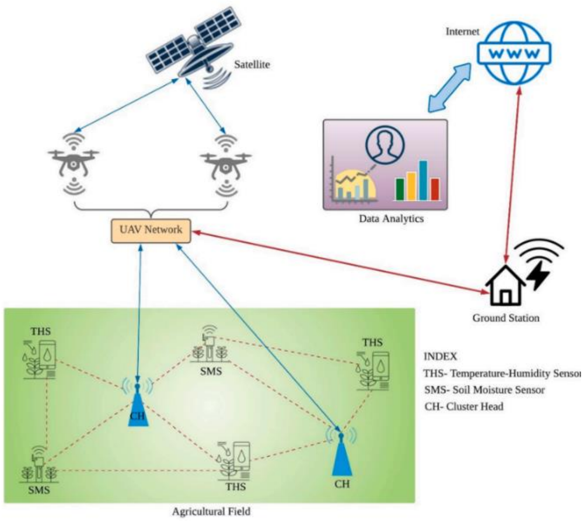

Figure 1: Integrated WSNs-UAVs-based IoT design for precision agriculture (Singh and Sharma 2022)

Furthermore, (Singh and Sharma 2022) present a proposed framework for integrating Wireless Sensor Networks (WSN) and Unmanned Aerial Vehicles (UAVs) to enhance precision agriculture. This framework sheds light on the essential requirements for constructing a dependable and robust WSN-UAV model designed for large-scale monitoring. It effectively tackles challenges associated with sensing and communication coverage by leveraging a range of radio links, from low data rates to high throughput, ensuring efficient data transmission over considerable distances while (Popescu et al. 2020) prioritizing energy and computational efficiency. This architecture comprises four operational layers: Ground level, edge intelligence, cloud intelligence, and data analytics, working in unison to process and interpret the collected data, offering valuable insights for informed decision-making in agriculture. According to (Rathinam et al. 2019) and (Singh and Sharma 2022) optimizing crop quality in agriculture via the Internet of Things (IoT) implies strategically placing sensor nodes equipped with various sensors such as soil,

temperature, humidity, ultrasonic, and CO2 sensors across the agricultural land. In addition to ground-based sensor networks, Unmanned Aerial Vehicles (UAVs) are equipped with sensors and imaging technologies that capture essential agricultural information from above.
These sensors include multispectral cameras for assessing crop health, thermal cameras for detecting temperature variations, (Delavarpour et al. 2021) LiDAR for creating 3D terrain maps, and GPS technology for precise georeferencing. It can count crops, monitor environmental factors like soil moisture and air quality, and provide real-time or stored data for analysis. Still, the primary difficulty that traditional Wireless Sensor Network (WSN) nodes confront is their limited energy capacity, which makes battery charge and replacement a challenging work. As (Bhatia, Jaffery and Mehfuz 2023) indicate, an intelligent placement method for sensor node positioning in IoT-WSN-enabled smart agriculture has been developed to overcome those energy-related concerns and maximize network performance. Computational methods such as Genetic Algorithm & PSO (Particle Swarm Optimization) are incorporated into this adaptive deployment method. These approaches optimize sensor node location to reduce energy consumption, hence extending the functionality of the network. Also, it includes explicit networking & multiple-hop transport techniques, significantly boosting network endurance by more than 100% on a typical basis.

IMPLEMENTATION IN BANGLADESH

In Bangladesh, where rural communities heavily rely on agriculture, the integration of Wireless Sensor Networks (WSN) and IoT-enabled devices holds tremendous transformative potential. By deploying IoT gadgets such as salinity sensors, soil moisture sensors, and weather sensors in their fields, farmers gain continuous access to vital data. This real-time information is transmitted to a web-based server, accessible to farmers through a dedicated app (Islam and Dey 2019) Given the pressing issues of water management and soil conditions, precise irrigation control and salinity monitoring are crucial. Through this integration, farmers can efficiently manage water resources, mitigate saltwater intrusion, and optimize soil health for crop cultivation. This remote monitoring capability empowers farmers to make informed decisions from a distance, ultimately boosting crop yields while conserving resources. (Chakraborty et al. 2022) The proposed system includes an offline monitoring component that collects data from temperature, humidity, light intensity, and soil moisture sensors onsite. This data is processed by a microcontroller and transmitted to the IoT platform via the Internet, enabling remote monitoring and control. Additionally, it can remotely manage the water pump in case of irrigation system issues. It operates independently and responds to soil moisture levels, ensuring timely and efficient water supply to the fields.

BENEFITS AND APPLICATION BARRIERS

There are benefits to implementing precision agriculture systems with wireless sensor networks and IoT architecture. For instance, it enables the producers to use technological advancements to enhance agricultural tracking management, which is critical for nations where farming is essential to the economy. (Islam and Dey 2019) The proposed systems' user-friendly interface facilitates farmer accessibility, allowing them to remotely monitor and take necessary actions based on the current conditions of their crop fields from the information gathered through sensors. The irrigation control model suggested by (Anguraj et al. 2021), uses wireless sensor networks (WSN) to collect real-time data on critical agricultural factors such as moisture content of the soil, weather, and crop data, allowing for precise and site-specific irrigation management. This results in more effective water use (Khriji et al. 2021), less environmental impacts, and maybe higher crop yields and quality.

The barriers include – the rising complexity of multiple stages of analysis and transmission is a significant challenge. Coordination of UAV (Popescu et al. 2020) operations with ground sensor networks necessitates precise coordination and connectivity, which can be time-consuming and heavy on resources in terms of logistics, (Chen, Chiang and Weng 2020) such as flight plan licenses for each UAV task. (Bhatia, Jaffery and Mehfuz 2023) has utilized algorithms (like genetic algorithm & particle swarm optimization) in smart agricultural models to optimize the lifespan of networks yield encouraging results. It is crucial to note, however, that the proportion of an increase in system lifespan could differ based on the dimensions of the topography & how far it deviates from the baseline range. One significant constraint is that performance evaluation has generally focused on the lifetime of networks alone.

RESEARCH GAPS AND QUESTIONS:

The following research gaps and questions have been identified to further explore the critical aspects of implementing innovative ideas in the agricultural sector:

GAPS:

- A research gap exists in understanding how to develop scalable and cost-effective IoT solutions tailored to the specific needs and resource constraints of developing nations' agricultural sectors.
- Concerns around data security and privacy require research, especially in areas with lenient laws & cybersecurity precautions.
- Addressing issues related to user acceptance and providing appropriate education for producers is essential.
- Evaluating the long-term viability and environmental impact of smart agriculture is imperative.

QUESTIONS:

1. How can adaptable and cost-effective IoT methods be designed and implemented to enhance farming practices in underdeveloped countries with limited resources?
2. What strategies and technologies can be employed to address data security and privacy risks associated with IoT-based agriculture, particularly in regions with poor regulatory oversight?
3. What are the key factors influencing user acceptance of IoT technologies in agriculture, and how can appropriate educational programs be designed to maximize the benefits of IoT for agricultural producers in regions that are developing?
4. What are the long-term viability and environmental implications of implementing smart agriculture solutions, and how can these be evaluated and mitigated effectively to promote sustainable agricultural practices?

REFERENCES:

1. Anguraj DK, Mandhala VN, Bhattacharyya D and Kim T-h (2021) 'Hybrid neural network classification for irrigation control in WSN based precision agriculture', *Journal of Ambient Intelligence and Humanized Computing*:1-12.
2. Bhatia S, Jaffery ZA and Mehfuz S 2023, *Development and Analysis of IoT based Smart Agriculture System for Heterogenous Nodes*, IEEE, 1665493828.
3. Cambra C, Sendra S, Lloret J and Lacuesta R (2018) 'Smart system for bicarbonate control in irrigation for hydroponic precision farming', *Sensors*, 18(5):1333.

4. Chakraborty A, Islam M, Dhar A and Hossain MS 2022, *IoT Based Greenhouse Environment Monitoring and Smart Irrigation System for Precision Farming Technology*, IEEE, 1665483970.
5. Chen P-C, Chiang Y-C and Weng P-Y (2020) 'Imaging using unmanned aerial vehicles for agriculture land use classification', *Agriculture*, 10(9):416.
6. Delavarpour N, Koparan C, Nowatzki J, Bajwa S and Sun X (2021) 'A technical study on UAV characteristics for precision agriculture applications and associated practical challenges', *Remote Sensing*, 13(6):1204.
7. *Global Issues - Population*, United Nations website, accessed 8/09/2023. https://www.un.org/en/global-issues/population#:~:text=Our%20growing%20population&text=The%20world's%20population%20is%20expected,billion%20in%20the%20mid%2D2080s.
8. Islam MS and Dey GK 2019, *Precision agriculture: renewable energy based smart crop field monitoring and management system using WSN via IoT*, IEEE, 1728160995.
9. Khriji S, El Houssaini D, Kammoun I and Kanoun O (2021) 'Precision irrigation: an IoT-enabled wireless sensor network for smart irrigation systems', *Women in Precision Agriculture: Technological Breakthroughs, Challenges and Aspirations for a Prosperous and Sustainable Future*:107-129.
10. Obaideen K, Yousef BA, AlMallahi MN, Tan YC, Mahmoud M, Jaber H and Ramadan M (2022) 'An overview of smart irrigation systems using IoT', *Energy Nexus*:100124.
11. Patil K and Kale N 2016, *A model for smart agriculture using IoT*, IEEE, 150900467X.
12. Popescu D, Stoican F, Stamatescu G, Ichim L and Dragana C (2020) 'Advanced UAV–WSN system for intelligent monitoring in precision agriculture', *Sensors*, 20(3):817.
13. Rathinam DDK, Surendran D, Shilpa A, Grace AS and Sherin J 2019, *Modern agriculture using wireless sensor network (WSN)*, IEEE, 1538695332.
14. Rejeb A, Abdollahi A, Rejeb K and Treiblmaier H (2022) 'Drones in agriculture: A review and bibliometric analysis', *Computers and Electronics in Agriculture*, 198:107017.
15. Singh PK and Sharma A (2022) 'An intelligent WSN-UAV-based IoT framework for precision agriculture application', *Computers and Electrical Engineering*, 100:107912.