Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

# A Hybrid Wireless Sensor Network for Smart Agriculture

Hayder Ayad Khudhair[1*]

[1] Ministry of Education, General Directorate for Education in Al-Najaf Al-Ashraf, 54001, Iraq.
E-mail: dr.hayder.ayad@gmail.com

*Corresponding author E-mail: dr.hayder.ayad@gmail.com

https://doi.org/10.46649/fjiece.v4.1.16a.25.3.2025

***Abstract.*** *The integration of Wireless Sensor Networks (WSNs) in agriculture has transformed precision farming, enabling monitoring and management of crops. However, traditional WSNs face challenges related to coverage, scalability, and adaptability to varying conditions. This study introduces a WSN architecture that combines terrestrial and aerial (drone-based) sensor nodes to enhance the efficiency of smart agriculture. While terrestrial nodes collect ground-level data, aerial nodes offer a perspective that can swiftly respond to changing environmental conditions. This combined approach optimizes resource allocation, enhances data accuracy, and ensures coverage. By conducting simulations and field tests, we assess the performance of the WSN in terms of coverage, energy efficiency, and throughput. The results indicate that hybrid WSNs significantly improve precision agriculture capabilities by providing a solution for real-time monitoring, efficient resource utilization, and timely decision-making. This study sets the stage for advancing cutting-edge farming technologies to meet the increasing need for productive agricultural practices.*

***Keywords:*** *HWSNs; Smart Agriculture; Precision Farming.*

## 1. INTRODUCTION

Farming is encountering difficulties because of climate change, limited resources, and the call for eco methods. Precision farming, which utilizes technology to enhance practices, has emerged as a solution [1]. Wireless sensor networks (WSNs) provide real-time data on soil conditions like moisture levels, temperature, and humidity. However, traditional WSNs using ground-based nodes encounter challenges such as coverage, energy consumption, and deployment complexities across various landscapes [2] [3]. The existing WSN setups in agriculture often face issues like coverage, node malfunctions, and energy inefficiencies. These obstacles impede the implementation of precision farming, resulting in inefficient resource management and crop cultivation [4]. To overcome these challenges, this study suggests a WSN structure that integrates. The goals of this research include designing a WSN architecture incorporating both ground-based and aerial sensors and assessing the performance of this network in terms of coverage area, energy efficiency, and data transmission speed to enhance data reliability. Additionally, the study aims to showcase how this hybrid WSN can be utilized in scenarios.

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

**The contributions** of this research can be summarized as follows:

1- proposing a novel hybrid WSN architecture,
2- Developing algorithms for efficient data collection and transmission in hybrid WSNs.
3- Provide empirical evidence of the benefits of hybrid WSNs through simulations and field experiments.

The rest of the paper is organized as follows: section 2 is for related works, section 3 illustrates Hybrid WSN Architecture Design, section 4 is for algorithm steps, section 5 explores Simulation and Evaluation, section 6 is for Conclusion and the references are in the last.

.

## 2. RELATED WORK

Agriculture is an important aspect of human life directly related to human health and resources such as water. Smart methods have been proposed to improve the supervision of agricultural processing. The authors in [5] employed a bibliometric analysis to explore the application of WSNs in agriculture, highlighting the significant growth of research in this area. It identifies key journals, authors, and studies and discusses the integration of WSNs with IoT, cloud computing, Artificial intelligence (AI), and Unmanned aerial vehicles (UAVs) for precision agriculture.

The authors in [6] conducted research showing that Wireless Sensor Networks (WSNs) were deployed in a wide range of farming applications, including soil monitoring, evaluation of corps health, and environmental monitoring. They regard traditional WSNs as dependent on constant terrestrial nodes, which are limited in coverage and flexibility.

The authors in [7] used drones with multiple sensors. The drones can fly to quickly cover large regions of farming soils and collect data from different latitudes and regions. This provides an integrated perspective to constant terrestrial sensors, which support farming monitoring precision and monitoring.

The authors in [8] explored the hybrid structure of Wireless Sensor Networks in other fields like environmental monitoring and disaster management. These structures aim to utilize from strength points of different types of sensors to support system performance comprehensively.

In [9], the authors confidently deal with Wireless Sensor Networks in precision agriculture. Focusing on how the sensor deployment affects the network, the research evaluates the malfunctions in the device's errors under real environmental conditions.

The authors in [10] conduct research that surveys Wireless Sensor Networks and IoT in agriculture and covers different precision agriculture practices such as Irrigation management, soil monitoring, and pest control, ensuring these techniques are incorporated.

Although the main emphasis is on healthcare in [10], this survey also delves into the integration of WSNs and IoT for agriculture, exploring their effectiveness in enhancing resource utilization and operational productivity.

The authors in [11] suggested a WSN design that combines wired and wireless elements to improve scalability and dependability in agricultural monitoring systems, tackling issues encountered in deploying sensor networks. In this paper, we propose a dual monitoring system concluding the earth and the sky, which provides an entire scan of the environmental characteristics around the area of interest. Table *1* is for a related works overview.

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

**Table 1. Overview of Related Works.**

| Ref. No. | Source Title | Publisher and Year | Technologies Used in Smart Agriculture |
|---|---|---|---|
| [5] | “Intelligent Wireless Sensor Networks for Precision Agriculture: A Review” | “Sensors”, 2020 | Intelligent Wireless Sensor Networks, Precision Agriculture Monitoring |
| [12] | Network lifetime improvement through energy-efficient hybrid routing protocol for iot applications | “Sensors”, 202١ | Wireless Sensor Networks, Agricultural Monitoring Systems, IoT Integration |
| [13] | Energy-Aware Routing in Wireless Sensor Networks | IEEE Transactions on Wireless Communications, 2020 | “Energy-Aware Routing, Wireless Sensor Networks”, Energy Efficiency |
| [8] | UAV-Based Multi-Source Data Fusion for Crop Growth Monitoring | IEEE Transactions on Geoscience and Remote Sensing, 2020 | UAV-Based Multi-Source Data Fusion, Crop Growth Monitoring, Remote Sensing |
| [9] | Reliability Analysis of Wireless Sensor Network for Smart Farming Applications | Sensors, 2021 | Reliability Analysis, Wireless Sensor Networks, Smart Farming Applications |
| [10] | Internet of Things and Wireless Sensor Networks for Smart Agriculture | IEEE Internet Things J, 2023 | “Internet of Things (IoT), Wireless Sensor Networks (WSN), Precision Agriculture” |
| [14] | “The Internet of Things for Health Care: A Comprehensive Survey” | “IEEE Access”, 2022 | Internet of Things (IoT), Hybrid Wireless Sensor Networks, Healthcare Applications |
| [11] | Hybrid Wireless Sensor Network Architectures for Smart Agriculture | IEEE Transactions on Industrial Informatics, 2024 | Hybrid Wireless Sensor Network Architectures, Smart Agriculture, Sensor Integration |

## 3. HYBRID WSN ARCHITECTURE DESIGN

This section provides an overview of the suggested system architecture. Figure 1, demonstrates the architecture of the suggested system design.

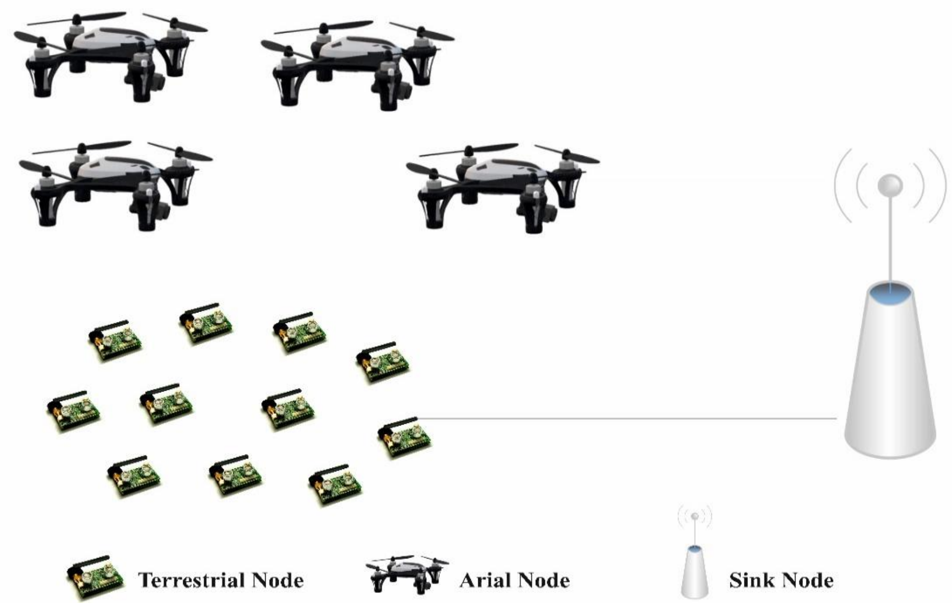


**Figure 1: Architecture of suggested system.**

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

*3.1 SYSTEM OVERVIEW*

The proposed hybrid “WSN architecture” consists of two basic components: terrestrial and aerial sensor nodes (drones). Terrestrial nodes are strategically placed throughout the agricultural field to monitor soil and plant conditions. Aerial nodes periodically fly over the field to collect additional data and provide an overview of the entire area.

*3.2 TERRESTRIAL SENSOR NODES (TSNS)*

Terrestrial sensor nodes come with sensors measuring soil moisture, temperature, humidity, and other important factors. These nodes rely on panels for power built to work independently, with little upkeep needed. They interact to create a network that guarantees data transfer to a base station.

*3.3 AERIAL SENSOR NODES (ASNS)*

Drones, also known as aerial sensor nodes, come with cameras and diverse sensors to collect information from the sky over the field. These drones stick to set flight routes. Can modify their paths depending on conditions. They interact with ground nodes and the main station to transmit data and get guidance.

*3.4 DATA FUSION AND PROCESSING*

Data collected from both terrestrial and aerial nodes are transmitted to a central base station, where it is processed and analyzed. Advanced data fusion techniques combine data from different sources, enhancing accuracy and providing comprehensive insights into field conditions. Figure 2, illustrates the suggested system block diagram, focus on the main components and their interactions, the system consists of six main units as follows:

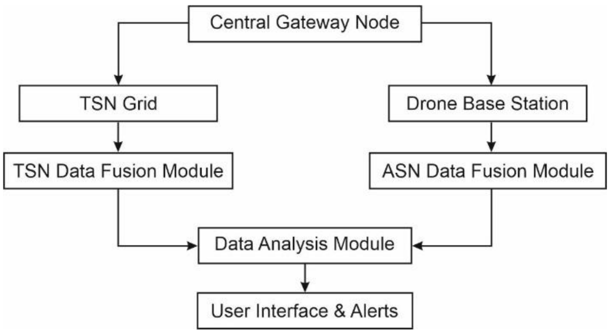


**Figure 2: a Block Diagram of the suggested system.**

## 4. APPROACH STEPS:

a. *INITIALIZATION:*

- Deploy TSNs in a grid pattern across the agricultural field.
- Schedule regular drone flights for ASNs based on predefined intervals and areas of interest.
- 

b. *DATA COLLECTION:*

- TSNs continuously monitor and collect data on soil moisture, temperature, humidity, etc.
- ASNs collect aerial images and data during flight missions, covering specified routes and areas.

*c. DATA FUSION:*

- Combine data from TSNs and ASNs to generate a comprehensive environmental profile.
- Use data fusion techniques to integrate terrestrial and aerial data, enhancing accuracy and coverage.

*d. ENERGY MANAGEMENT:*

- Implement power-saving modes for TSNs, activating sensors only when necessary or based on environmental triggers.
- Optimize drone flight paths and schedules to conserve battery life while maximizing coverage.

*e. COMMUNICATION PROTOCOL:*

- Establish a hierarchical communication structure where TSNs communicate with a central gateway node.
- ASNs transmit data to the central gateway upon returning to a charging station or base.

*f. REAL-TIME ANALYSIS AND DECISION MAKING:*

- Use machine-learning models to analyze fused data for real-time decision-making, such as irrigation control, pest management, and crop health assessment.
- Generate actionable insights and recommendations based on the analysed data.

*g. FAULT TOLERANCE AND MAINTENANCE:*

- Implement self-check algorithms for TSNs and ASNs to detect and report faults or malfunctions.
- Schedule maintenance for ASNs and replace or repair faulty TSNs promptly.

*h. USER INTERFACE AND ALERTS:*

- Develop a user-friendly interface for farmers to monitor real-time data and insights.
- Send alerts and notifications for critical conditions, such as drought stress, pest infestation, or equipment failure. Figure 3: represents a flow chart for the suggested system.

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

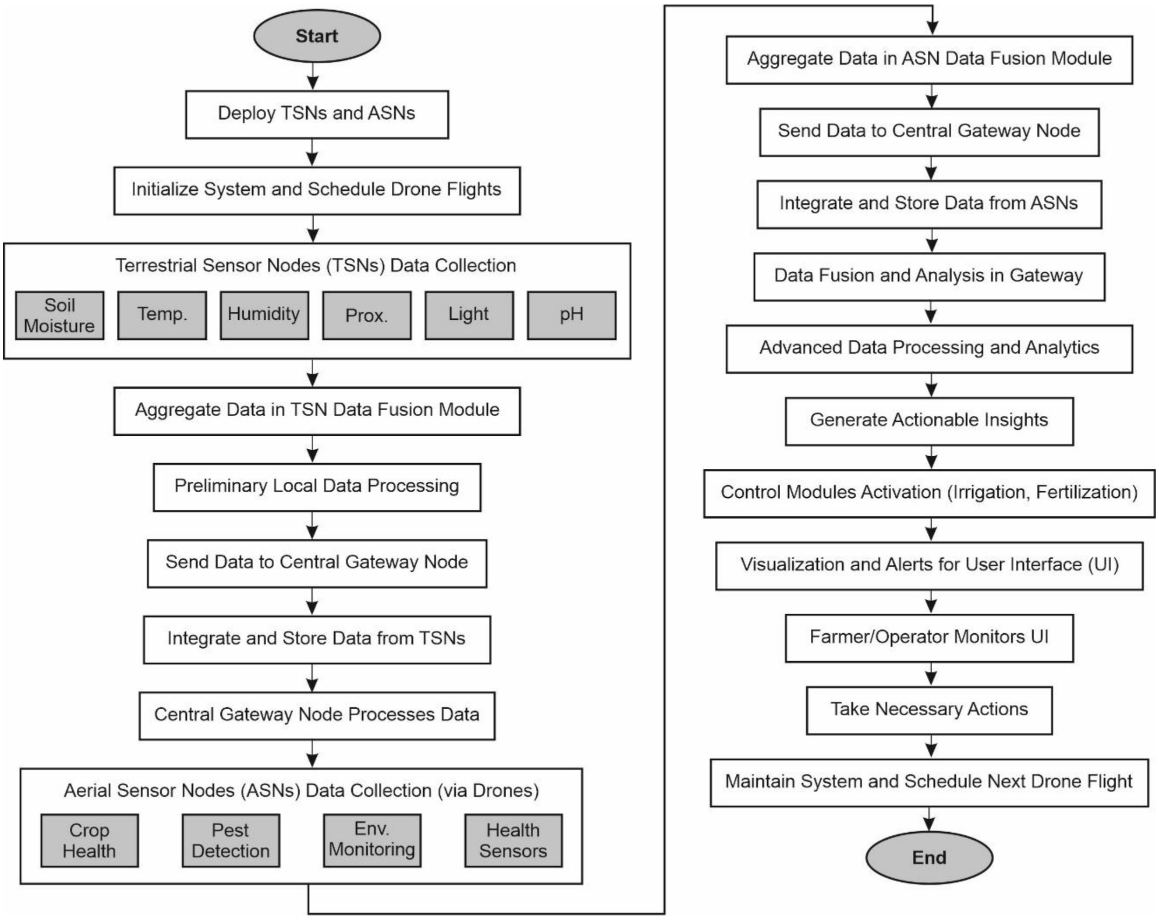


**Figure 3: represents a flow chart for the suggested system.**

## 5. SIMULATION AND EVALUATION

In the context of this research, a comprehensive review of related works is done to find similar related works that depended on the same structure, environment, and standards used in this work, including coverage, energy efficiency, and throughput. However, we could not find related works that comprehensively correspond with our structure and standards to compare with. This lake in literature focuses on the research gap in this field. It reinforces the importance of current work that seeks to fill this gap by introducing comprehensive and detailed analysis depending on the current specified standards.

### *5.1 SIMULATION SETUP*

Simulations are conducted to evaluate the performance of the hybrid WSN architecture under various scenarios. The simulation environment replicates a typical agricultural field with different crop types and terrain. Table 2, contains parameters used in the simulation.

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

**Table 2: Simulation Parameters.**

| Parameters | Terrestrial Parameters | Arial Parameters |
|---|---|---|
| **Number of Nodes** | 25 nodes | 10 nodes |
| **RoI(L*W*H)** | 1000m*1000m | 1000m*1000m*80m |
| **Sensing Diameter** | 10m | 55m |
| **Transmission Range** | 30m | 100m |

### *5.2 PERFORMANCE METRICS*

The performance of the hybrid WSN is assessed based on several metrics, including, coverage, energy efficiency, and throughput. Table 3, clarifies the simulation results.

**Table 3: Simulation Results.**

| Number of Ticks | Energy Efficiency | Throughput | Coverage |
|---|---|---|---|
| 0 | 100 | 100 | 0.7845 |
| 50 | 87 | 88 | 0.6281 |
| 100 | 74 | 73 | 0.5221 |
| 150 | 44 | 59 | 0.4884 |
| 200 | 14 | 43 | 0.3974 |

Below are general demonstrations for each metric followed by a figure to represent the simulation results visually with discussion.

**a.** *COVERAGE:* The extent to which the sensor nodes monitor the field [15]. At least one sensor must monitor any point in the Region of Interest. The RoI is said to be covered if every point in the Region of Interest is in the covering area [16]. The coverage rate is a value in the range from 0 to 1 computed by dividing the "covered area" into the overall Region of Interest. As WSNs operate over time, coverage may change due to node failures, energy depletion, or environmental conditions [17], [18]. Figure 4, represents network coverage through time. Generally, coverage can be computed by:

$$Coverage = Covered\ Area/Overall\ Area.$$

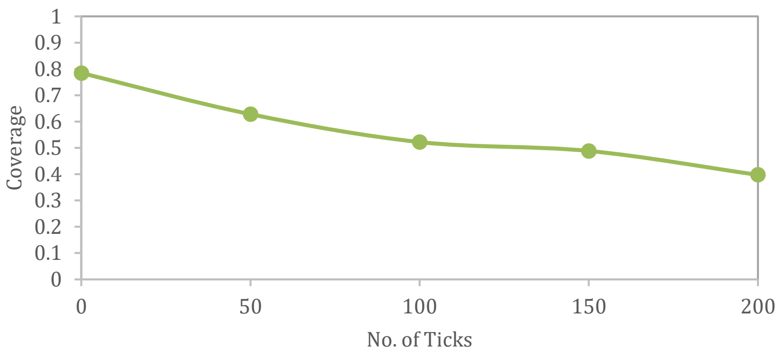


**Figure 4: Network Coverage.**

Al-Furat Journal of Innovations in Electronics and Computer Engineering (FJIECE)
ISSN -2708-3985

Depending on the results achieved from the simulation, we demonstrate that the coverage decreases through time depending on the node failure by running out of energy through time, so we diagnose the following equation (1) using regression analysis to calculate the energy depending on time:

$$y = mx + b \qquad (1)$$

Where:

(y) Represents the "Coverage."
(x) Represents the "No. of Ticks."
(m) Is the slope (indicating how much "Coverage" changes per unit increase in "No. of Ticks").
(b) is the y-intercept (the value of "Coverage" when there are no ticks).
We can simplify it further by assuming that the slope ((m)) is negative. Let's express it as in (2):

$$\mathbf{y = -0.005x + 1} \qquad (2)$$

This equation captures the decreasing relationship between "Coverage" and "No. of Ticks."

**b.** *ENERGY EFFICIENCY:* The amount of "energy consumed" by the sensor nodes.
The Energy Efficiency depends on many factors:

I. Nodes Energy Consuming: All sensors must be measured for energy consumption during sensing, processing, and communication. Energy consumption meters can be used to determine these values [19].
II. Wireless Communicating Energy Consuming: there is also a need to measure the energy consumed during wireless communication among nodes, this is composed of energy consumed during the send and receive traffic and data [20].
III. Routing and Protocols: using suitable routing algorithms and protocols to enhance energy efficiency by specifying efficient routes and using low energy-consuming data transmission are a portion of these strategies [21].
IV. Coverage and Deployment: the sensor deployment must be good and efficient to monitor the cover overall interested region, simulation models an be used to specify the best deployment strategy.
V. Energy Controlling: using energy-controlling techniques such as standby and smart wakeup to minimize energy consumption when the sensors are inactive.

In the last, the balance between energy consumed and network performance to achieve the best efficiency [22], [23]. Figure 5 represents network "energy efficiency".

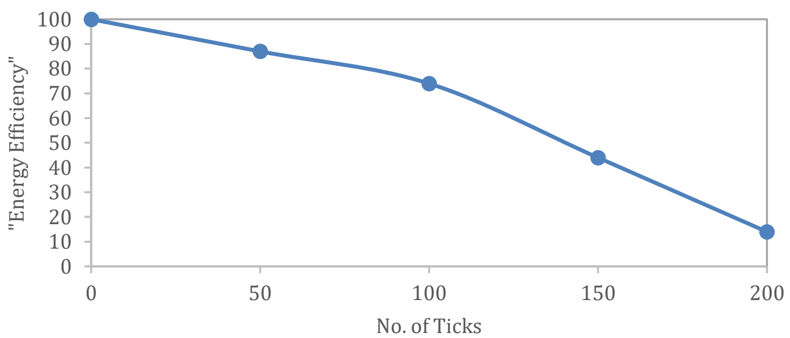


**Figure 5: Network Energy Efficiency.**

Depending on the results achieved from the simulation, we demonstrate that the energy decreases through time. Many factors affect the network and because this decrease such as energy consumed by sensors to support the electronics parts such as receiver and transmitter and sensing parts, energy lost by batteries itself through time by environmental changes, and errors in sending data will consume more energy to re-send data again to the destination.

**c.** *THROUGHPUT***:** Measured by an average of data transmitted via a network in seconds. Throughput is considered an important success factor in Wireless Sensor Networks, or it is the transmission of protocols through a specified period [24]. Another meaning is the amount of data that is transmitted successfully and forwarded to the upper layer of the network through a specified time [25]. That is means if throughput is high, the network able to speedily Trans large amounts of data. On the other hand, if the throughput was low that means maybe there is a jam in data and a delay in data receiving. Figure 6, represents network throughput, the following equation (3) used to calculate throughput [26] [27]**.**

$$\text{Throughput} = \frac{Total\ data\ successfully\ delivered(kb)}{Time\ taken\ to\ deliver\ data(s)} \qquad (3)$$

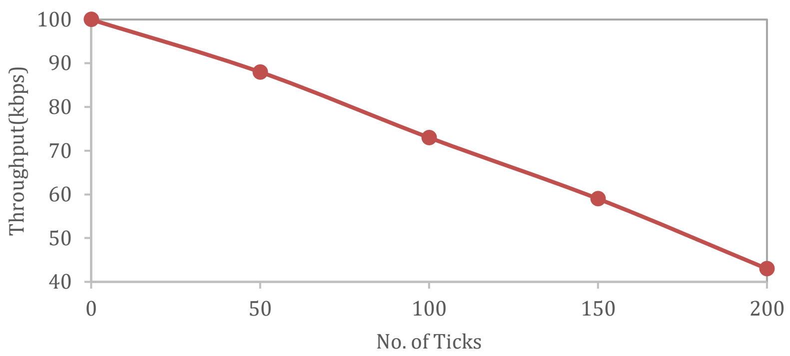


**Figure 6: Network throughput/kbps.**

According to the above plot, we found that throughput decreased with time (Ticks). This mentions the inverse relation between time and performance in the hybrid network; in other words, as ticks increase, throughput will decrease. This degradation is caused by many factors, such as energy limitations, environmental interferences, and wireless interferences.

## 6. CONCLUSION

This research presents a novel hybrid WSN architecture for smart agriculture, combining terrestrial and aerial sensor nodes to address the limitations of traditional WSNs. The simulations and field experiments demonstrate that the hybrid WSN significantly improves coverage, the accuracy and completeness of collected data, and energy efficiency. Data is gathered gradually to assess how well the hybrid WSN performs. The gathered data is studied to determine how effective the hybrid design is, in enhancing methods. This new system provides a solution for monitoring and managing agriculture in time supporting sustainable and efficient farming techniques. The hybrid WSN structure has advantages compared to WSNs, such as better coverage and scalability, increase data accuracy through data fusion, and improve adaptability to changing environmental conditions. Despite its benefits challenges faced by the WSN architecture include initial deployment costs, complexities, in handling a large number of sensor nodes, and potential issues with drone operation during unfavourable weather conditions.

Future research can focus on developing more cost-effective hybrid WSN solutions by enhancing the robustness of drones for operation in extreme conditions and integrating advanced AI techniques for predictive analytics and automated decision-making.

## REFERENCES

[1] Li, Yang, and Yin, "Hybrid wireless sensor networks: A comprehensive survey," *IEEE Access*, vol. 8, pp. 61125–61139, 2020, doi: 10.1109/ACCESS.2020.2984895.

[2] H. Ayad Khudhair, "Optimal Drone Nodes Deployment to Maximize Coverage and Energy in WSNs Using Genetic Algorithms," *Journal of Al-Qadisiyah for Computer Science and Mathematics*, vol. 16, no. 1, Mar. 2024, doi: 10.29304/jqcsm.2024.16.11434.

[3] O. Gulec, "Extending lifetime of Wireless Nano-Sensor Networks: An energy efficient distributed routing algorithm for Internet of Nano-Things," *Future Generation Computer Systems*, vol. 135, pp. 382–393, 2022, doi: https://doi.org/10.1016/j.future.2022.05.009.

[4] Smith and Thompson, "Hybrid routing protocols for underwater wireless sensor networks: A survey," *Sensors*, 2023.

[5] M. R. Asghar, H. Mohamad, and A. Abdullah, "Intelligent Wireless Sensor Networks for Precision Agriculture: A Review," *Sensors*, vol. 20, no. 5, p. 1424, 2020.

[6] S. Smith and T. Thompson, "Hybrid routing protocols for underwater wireless sensor networks: A survey," *Sensors*, 2023.

[7] P. Bekal, P. Kumar, P. R. Mane, and G. Prabhu, "A comprehensive review of energy efficient routing protocols for query driven wireless sensor networks," *F1000Res*, vol. 12, p. 644, Jun. 2023, doi: 10.12688/f1000research.133874.1.

[8] F. Tao, Y. Cheng, Y. Wang, Y. Xu, and H. Gu, "UAV-Based Multi-Source Data Fusion for Crop Growth Monitoring," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 58, no. 4, pp. 185–199, 2020.

[9] A. Bartolini, C. Del Rio, G. Guidi, and G. Patrizi, "Reliability Analysis of Wireless Sensor Network for Smart Farming Applications," *Sensors*, vol. 21, no. 22, p. 7683, 2021, doi: 10.3390/s21227683.

[10] R. A. Martínez, H. Martín, R. Martínez, and R. Sarmiento, "Internet of Things and Wireless Sensor Networks for Smart Agriculture," *IEEE Internet Things J*, vol. 10, no. 5, pp. 4214–4223, 2023.

[11] Y. Li, J. Zhang, and X. Wang, "Hybrid Wireless Sensor Network Architectures for Smart Agriculture," *IEEE Trans Industr Inform*, vol. 20, no. 2, pp. 1530–1541, 2024.

[12] M. Mishra, G. Sen Gupta, and X. Gui, "Network lifetime improvement through energy-efficient hybrid routing protocol for iot applications," *Sensors*, vol. 21, no. 22, Nov. 2021, doi: 10.3390/s21227439.

[13] R. Jurdak, P. Baldi, and C. V. Lopes, "Energy-Aware Routing in Wireless Sensor Networks," *IEEE Trans Wirel Commun*, vol. 23, no. 5, pp. 106–112, 2020.

[14] S. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. S. Kwak, "The Internet of Things for Health Care: A Comprehensive Survey," *IEEE Access*, vol. 7, pp. 3458–3470, 2022, doi: 10.1109/ACCESS.2018.2883305.

[15] A. Abbasi and M. Younis, "A Survey on Clustering Algorithms for Wireless Sensor Networks," *Comput Commun*, vol. 30, pp. 2826–2841, Oct. 2007, doi: 10.1016/j.comcom.2007.05.024.

[16] G. Chen, C. Li, M. Ye, and J. Wu, "An unequal cluster-based routing protocol in wireless sensor networks," *Wireless Networks*, vol. 15, no. 2, pp. 193–207, 2009, doi: 10.1007/s11276-007-0035-8.

[17] H. Khudhair, “Dynamic Load-Balanced Sink Placement (DLBSP) Algorithm for WSNs in IoT,” *Journal of Education for Pure Science- University of Thi-Qar*, vol. 14, no. 4, Dec. 2024, doi: 10.32792/jeps.v14i4.500.

[18] H. Khudhair, “An Adaptive Activity Cycling Technique for Energy Management in Wireless Sensor Networks (WSNs),” *Wasit Journal of Computer and Mathematics Science*, vol. 3, no. 3, pp. 1–10, Sep. 2024, doi: 10.31185/wjcms.256.

[19] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, “Energy-Efficient Communication Protocol for Wireless Microsensor Networks,” 2000.

[20] C. Del-Valle-soto, C. Mex-Perera, J. A. Nolazco-Flores, A. Rodríguez, J. C. Rosas-Caro, and A. F. Martínez-Herrera, “A low-cost jamming detection approach using performance metrics in cluster-based wireless sensor networks,” *Sensors (Switzerland)*, vol. 21, no. 4, pp. 1–28, Feb. 2021, doi: 10.3390/s21041179.

[21] X. Ju, A. Souri, and M.-Y. Chen, “Energy-efficient routing sensing technology of wireless sensor networks based on Internet of Things,” *Journal of High Speed Networks*, vol. 27, no. 3, pp. 225–235, Aug. 2021, doi: 10.3233/JHS-210663.

[22] K. Naithani and A. Professor, “Performance Analysis Of Energy Efficient Protocols For Wireless Sensor Networks,” vol. 20, no. 4, pp. 4852–4864, 2021, doi: 10.17051/ilkonline.2021.04.520.

[23] H. H. El-Sayed, E. M. Abd-Elgaber, E. A. Zanaty, and S. S. Bakheet, “A Modified LEACH Protocol Using Multi-Hop Mechanism and Neural Networks for IoT Applications,” *Sohag Journal of Sciences*, vol. 9, no. 3, pp. 274–285, Sep. 2024, doi: 10.21608/sjsci.2024.227091.1107.

[24] A. A. Jasim, M. Y. I. Idris, S. Razalli Bin Azzuhri, N. R. Issa, M. T. Rahman, and M. F. b Khyasudeen, “Energy-Efficient Wireless Sensor Network with an Unequal Clustering Protocol Based on a Balanced Energy Method (EEUCB),” *Sensors*, vol. 21, no. 3, 2021, doi: 10.3390/s21030784.

[25] A. Kundaliya, S. Kumar, and D. K. Lobiyal, “Throughput and Lifetime Enhancement of WSNs Using Transmission Power Control and Q-learning,” *Wirel Pers Commun*, vol. 132, no. 2, pp. 799–821, 2023, doi: 10.1007/s11277-023-10622-x.

[26] H. A. Khudhair, A. T. Albu-Salih, M. Q. Alsudani, and H. F. Fakhruldeen, “A clustering approach to improve VANETs performance,” *Bulletin of Electrical Engineering and Informatics*, vol. 12, no. 5, pp. 2978–2985, 2023, doi: 10.11591/eei.v12i5.5086.

[27] I. Surenther, K. P. Sridhar, and M. Kingston Roberts, “Maximizing energy efficiency in wireless sensor networks for data transmission: A Deep Learning-Based Grouping Model approach,” *Alexandria Engineering Journal*, vol. 83, pp. 53–65, 2023, doi: https://doi.org/10.1016/j.aej.2023.10.016.