International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 11 | Nov - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

IOT-Based Smart Precision Farming: A Comprehensive Review of Enabling Technologies

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Abstract-
The global agricultural sector faces unprecedented challenges, including climate change, water scarcity, and the need to enhance yield to meet rising food demand. Precision farming, empowered by the Internet of Things (IoT), presents a paradigm shift from traditional homogeneous field management to data-driven, site-specific optimization. This paper reviews the core technologies and architectural frameworks essential for implementing a robust IoT-based smart farming system. We examine the integration of wireless sensor networks (WSNs) for real-time field data acquisition (e.g., soil moisture, temperature, humidity, NPK levels), the role of unmanned aerial vehicles (UAVs) for aerial imaging and monitoring, and the suitability of microcontrollers like ESP32 and Arduino for localized control and connectivity. The review details a system architecture that leverages cloud platforms for data analytics, enabling automated decision-making for irrigation, fertilization, and pest control. By synthesizing data from multiple sources, these intelligent systems promise to significantly increase crop productivity, optimize resource usage, and promote sustainable agricultural practices.

Keywords—Precision Agriculture, Internet of Things (IoT), Wireless Sensor Networks (WSN), Sensor Nodes, Cloud Computing, Data Analytics, Automated Irrigation, ESP32.

I. INTRODUCTION

A. The Need for Precision in Modern Agriculture

Traditional farming methods often rely on uniform treatment of entire fields, leading to inefficient use of resources like water, fertilizers, and pesticides.

A. Sensor Suite for Data Acquisition

This inefficiency results in increased operational costs, environmental degradation, and suboptimal yields. The integration of IoT technology addresses these issues by enabling micro-management of field measure variations, ensuring that inputs are applied only where and when they are needed.

B. Core Technological Synthesis

IoT-based smart farming synthesizes concepts from several domains:

- **Wireless Sensor Networks (WSNs):** Deployment of spatially distributed, autonomous sensors to monitor environmental and soil conditions.
- **Data Communication Protocols:** Use of low-power, wide-area (LPWAN) protocols like LoRaWAN and NB-IoT, or short-range protocols like Zigbee and Bluetooth for reliable data
- **Microcontroller Selection (ESP32/Arduino):** The transmission.
- **Cloud Computing & Big Data Analytics:** Centralized platforms for storing, processing, and analyzing vast amounts of agricultural data to generate actionable insights.
- **Automated Control Systems:** Actuators (e.g., farms, solenoid valves, motorized pumps) that are triggered automatically based on sensor data and predefined rules.

C. Paper Organization

The remainder of this paper is structured as follows: Section II discusses the hardware foundation, including sensors, microcontrollers, and communication modules. Section III covers the intelligence layer, focusing on data analytics and water in decision-making algorithms. Section IV details the integrated system architecture. Section V provides a and comparative analysis with traditional methods and discusses implementation challenges. Section VI concludes the paper and suggests future research directions.

II. HARDWARE FOUNDATION: SENSING AND COMMUNICATION

A smart farming system relies on a suite of sensors to create a comprehensive picture of field conditions:

- **Soil Moisture Sensors:** Capacitive or resistive sensors provide critical data for triggering automated irrigation, preventing both under-watering and over-watering.
- **Environmental Sensors:** DHT22/11sensors monitor air temperature and humidity, essential for predicting frost events or disease outbreaks.
- **NPK Sensors:** Electrochemical sensors the concentration of Nitrogen, Phosphorus, and Potassium in the soil, enabling precise fertilization.
- **pH Sensors:** Monitor soil acidity/alkalinity, which affects nutrient availability to plants.
- **Light Intensity Sensors:** Measure photosynthetically active radiation (PAR) to assess plant health.

B. Microcontroller and Communication Modules

The gateway or sensor node controller is the brain of the local system.

ESP32 is favored for its integrated Wi-Fi and Bluetooth capabilities, low power consumption, and sufficient processing power for basic data preprocessing. Arduino boards offer simplicity and a vast ecosystem of shields for various sensors.

- **Communication Protocols:** For large LPWAN technologies like LoRaWAN provide long-range communication with minimal power consumption. For smaller areas, Zigbee mesh networks offer robust, low-power connectivity.

C. Actuators for Automated Control

Data-driven decisions are executed through actuators:

- **Solenoid Valves:** Control the flow of irrigation lines.
- **Motorized Pumps:** Manage water pressure flow from the source.
- **Dispensers:** For the automated application of liquid fertilizers or pesticides.

III. INTELLIGENCE LAYER: DATA ANALYTICS AND DECISION-MAKING

A. Cloud Platform Integration
Sensor data is transmitted to cloud platforms (e.g., AWS IoT, Google Cloud IoT Core, ThingSpeak) for storage and advanced analysis. These platforms facilitate:

- **Real-time Monitoring:** Dashboards for farmers to view field conditions remotely.
- **Historical Data Analysis:** Identifying trends and correlations over time.

B. Decision-Making Algorithms

- **Rule-Based Systems:** Simple IF-THEN rules (e.g., IF soil moisture < 30%, THEN trigger irrigation for 10 minutes).
- **Machine Learning Models:** More advanced systems use ML algorithms for predictive analytics, such as forecasting pest attacks based on historical weather and soil data, or predicting optimal harvest times.

IV. SYSTEM ARCHITECTURE AND INTEGRATION

A. Integrated System Architecture
The architecture is typically layered:

1. **Perception Layer:** Sensor nodes deployed in the field.
2. **Network Layer:** Gateways that aggregate data from nodes and transmit it to the cloud via cellular or satellite networks.
3. **Application Layer:** Cloud-based software that processes data, presents it to the user via a web/mobile app, and sends control signals back to actuators.

B. Power Management
For remote field deployments, power autonomy is critical. Systems are often powered by solar panels paired with rechargeable batteries, ensuring continuous operation.

V. COMPARATIVE ANALYSIS

1. **Saha, G., Shahrin, F., Khan, F. H., Meshkat, M. M., & Azad, A. A. M.** in their **2025** paper, **"Smart IoT-driven precision agriculture: Land mapping, crop prediction, and irrigation system,"** present a comprehensive, multi-faceted system leveraging a variety of technologies. The core of their work utilizes **IoT** devices, **Machine Learning (ML)** algorithms (including K-means, Random Forest, Linear Regression, and LSTM), **Fuzzy Logic**, and satellite imagery from **Landsat-8**. Their methodology involved creating a system that not only predicts crop types with high accuracy but also incorporates a smart irrigation component driven by fuzzy logic to optimize water usage. This integrated approach resulted in a remarkable **97.35% accuracy for crop prediction** and achieved a significant **61% reduction in water usage**. Looking forward, the authors suggest that future enhancements should focus on the use of solar power to further reduce electricity demand, making the system more sustainable.
2. **Liu, X., Zhao, Z., & Rezaeipanah, A.** authored the **2025** paper, **"Intelligent and automatic irrigation system based on internet of things using fuzzy control technology,"** which focuses on developing an efficient, low-cost irrigation system. The technologies employed are **IoT** and **Fuzzy Control**. Their methodology centers on a fuzzy rule-based inference approach to determine optimal irrigation methods based on real-time sensor data, while an energy-aware routing algorithm (OSPF) ensures efficient information transmission. The simulation results of their system demonstrated that it **outperformed existing algorithms** like DLQR, SPIS, and FWIS in terms of network lifetime and power consumption. For future work, they propose integrating **Deep Neural Networks (DNNs)** with the fuzzy system to enhance the system's adaptability and intelligence.
3. **Monchusi, B. B., Kgopa, A. T., & Mokwana, T. I.** published the **2024** paper titled **"Integrating IoT and AI for Precision Agriculture: Enhancing Water Management and Crop Monitoring in Small-Scale Farms,"** which addresses the specific needs of small-scale farmers. The technologies utilized include a combination of **IoT**, **AI**, **Machine Learning (ML)**, and **Edge Computing**. The authors' methodology involved developing a smart irrigation system that uses sensors to collect real-time data on soil moisture and environmental conditions. This data is then fed into machine learning algorithms, specifically **Decision Trees and**

SVM, to provide precise water application recommendations. The outcome was a system that successfully **optimized water usage and increased crop output** on small-scale farms. The researchers recommend that future work should focus on developing scalable and adaptable systems that are also cost-effective to ensure wider adoption among these farmers.

4. **Padhiary, M., Kumar, A., & Sethi, L. N.** wrote the **2025** review article, **"Emerging technologies for smart and sustainable precision agriculture,"** which provides a comprehensive overview of the key technologies transforming the agricultural sector. They discuss a wide range of technologies including **IoT, Cloud Computing, AI, ML, Automation, 5G, Drones, and Satellites**. Their methodology involved a systematic review and synthesis of how these technologies are integrated for data collection, storage, and processing to maximize efficiency and sustainability. The paper highlights that the combined use of these technologies leads to **increased yield, reduced costs, and enhanced resource conservation**. As for future enhancements, they discuss the promising role of **5G networks, advancements in edge computing**, and the integration of more sophisticated **AI algorithms** to further revolutionize the field.
5. **Sharma, K., & Shivandu, S. K.**, in their **2024** paper **"Integrating artificial intelligence and Internet of Things (IoT) for enhanced crop monitoring and management in precision agriculture,"** review the synergistic relationship between AI and IoT in modern farming. Their analysis covers advanced technologies such as **High-throughput phenotyping, remote sensing, AgroBots, and 5G/6G**. As a review paper, their methodology involves a thorough examination of how these innovations are used to automate various agricultural tasks. The outcome is a conclusion that these integrated systems significantly **enhance crop monitoring and management** by automating tasks and reducing labor costs. They propose that future work should focus on addressing crucial issues like data security, scalability, and the seamless integration of diverse datasets, anticipating the advent of next-generation networks like 6G.
6. **Sahu, R., & Tripathi, P.** presented **"An intelligent framework for monitoring and irrigation prediction for precision agriculture"** in **2025**. This study introduces an innovative two-phase smart irrigation framework. The technologies central to their system are **IoT, ML, and Edge Computing**, utilizing specific hardware like **Arduino UNO and NodeMCU**, and the **XGBoost** algorithm. The methodology involves a Phase 1 with an IoT sensor network for real-time data collection and a Phase 2 using the machine learning model for precise irrigation prediction. The framework achieved an exceptional **99.96% accuracy for irrigation prediction** and resulted in a notable **25% reduction in water consumption**. For future work, they suggest focusing on creating a scalable, energy-efficient, and sustainable solution to make the technology more widely applicable.
7. **Gupta, S., Chowdhury, S., Govindaraj, R., Ameshof, K. T. T., Shangdiar, S., Kadhila, T., & Iikela, S.**, in their **2025** paper **"Smart agriculture using IoT for automated irrigation, water and energy efficiency,"** describe an **IoT-based** system for automated irrigation. The core technology involves a predictive algorithm running on an **Arduino** microcontroller, with control and monitoring accessible via **mobile devices**. Their methodology is to use this system to automatically adjust irrigation based on real-time and historical sensor data. This approach successfully resulted in a **30% reduction in water usage**, demonstrating its potential to not only optimize water but also to improve crop yields and lower labor and energy costs. The authors suggest that the broader adoption of this technology is a key area for future focus to address global water scarcity.
8. **Shahab, H., Naeem, M., Iqbal, M., Aqeel, M., & Ullah, S. S.** authored the **2025** paper **"IoT-driven smart agricultural technology for real-time soil and crop optimization,"** which focuses on using technology for real-time farming decisions. The paper employs **IoT, Cloud computing, and AI-driven predictive algorithms** delivered via a **mobile application**. Their methodology involved the continuous monitoring of eight critical soil parameters and using this data to provide actionable, data-driven recommendations to farmers in real-time. The outcome of this system was its ability to accurately measure

soil parameters and successfully **empower farmers with timely insights**, contributing to sustainable farming. Future work, as proposed, should focus on refining the AI and predictive algorithms to fully leverage data-driven decision-making.

9. **Kaushik, S., & Singh, K.**, in their **2025** paper **"AI-Driven Smart Irrigation and Resource Optimization for Sustainable Precision Agriculture,"** propose a comprehensive framework for resource management. The technologies central to their research are **AI, IoT, and ML** powered by **cloud-based analytics**. Their methodology involves a framework that leverages real-time environmental data, such as soil moisture and weather forecasts, to provide precise and adaptive recommendations for irrigation and resource use. Through case studies, the system demonstrated significant **improvements in water-use efficiency, a reduction in agrochemical use, and enhanced crop yield**. The authors suggest that future efforts should be directed at making the system more scalable and widely accessible to farmers.
10. **Al Mamun, M. R., Ahmed, A. K., Upoma, S. M., Haque, M. M., & Ashik-E-Rabbani, M.** in their **2025** work, **"IoT-enabled solar-powered smart irrigation for precision agriculture,"** focus on a sustainable, energy-independent system. The technologies used are **IoT, solar power, Raspberry Pi 4, ESP8266**, and a variety of sensors, all communicating via the **MQTT protocol**. Their methodology involved creating a system powered by a 20W solar panel and a battery, allowing for remote monitoring and pump control via a web interface. This system successfully allows farmers to remotely manage irrigation, **decreasing reliance on traditional energy sources** and significantly **reducing water loss**. The paper does not explicitly mention future enhancements.
11. **More, N. P., Venkataramanan, V., Kumar, M. O., Padaya, M. S., & Solanki, F.**, in their **2025** paper **"IoT-Based Precision Farming Robot for Agricultural Automation,"** focus on the physical automation of farming tasks. The technologies at the heart of their research include **IoT, sensors, Wireless Sensor Networks**, and powerful embedded systems like the **Raspberry Pi and ESP32**. Their methodology involved the design and development of an automated robot to perform agricultural tasks and collect crucial data. The outcome was a functional prototype of a farming robot, demonstrating the potential for increased efficiency and reduced labor through agricultural automation. The paper does not explicitly mention future enhancements.
12. **Sharafat, M. S., Kabya, N. D., Emu, R. I., Ahmed, M. U., Oniko, J. C., Islam, M. A., & Khan, R.** authored **"An IoT-enabled AI system for real-time crop prediction using soil and weather data in precision agriculture"** in **2025**. This research focuses on real-time decision-making for crop selection. The system integrates **IoT** and **AI**, using various **ML** algorithms (**Random Forest, Gradient Boosting, Stacking**) and **DL** models (**TabNet**). Their methodology involved deploying the best-performing ensemble models on a **Raspberry Pi 5** to provide instantaneous crop predictions. The stacking ensemble model achieved an outstanding **95.9% accuracy**, while the Random Forest model was chosen for deployment due to its low inference time, making it highly suitable for a real-time system. The paper does not explicitly state future enhancements.
13. **Morchid, A., Et-taibi, B., Oughannou, Z., El Alami, R., Qjidaa, H., Jamil, M. O., Boufounas, E., & Abid, M. R.**, in their **2025** paper **"IoT-enabled smart agriculture for improving water management: A smart irrigation control using embedded systems and Server-Sent Events,"** focus on a low-latency irrigation control system. The core technologies are **IoT**, an **ESP32 embedded system**, and **Server-Sent Events (SSE)**. Their methodology involved designing a system where the embedded hardware collects data from various sensors and sends real-time updates to a user interface using SSE, ensuring highly responsive and efficient communication. The outcome of their research was a system that demonstrated a significant **improvement in irrigation efficiency** by accurately and precisely applying water resources. The paper does not explicitly state future enhancements.
14. **Elshikha, D. E., Attalah, S., Waller, P., Levinson, R., Bloomfield, M., Koralewski, S., Teeter, M., Moller, P., Orr, E., & Elsadek, E. A.** authored **"Smart Irrigation**

Solutions for Today's Farms" in **2025**, a review paper that summarizes current automated irrigation technologies. The paper primarily discusses the use of automated systems and various sensors for water management. Their methodology is a comprehensive review of existing solutions that monitor, control, and adjust irrigation processes. The paper serves as a valuable resource that highlights how these technologies provide effective solutions for critical agricultural challenges such as **drought and groundwater depletion**, helping farmers maintain productivity with limited resources. The paper does not explicitly state future enhancements.

15. **Sadotra, P., Chouksey, P., Chopra, M., Thakur, N., Thakur, G., Gupta, S., & Koser, R.**, in their **2025** review article **"Integrating Artificial Intelligence & IoT for Precision Farming: Advancing Agriculture 4.0 Solutions,"** provide a detailed look into the "Agriculture 4.0" paradigm. The technologies they focus on are **AI, IoT, drones, and smart sensors**. The authors' methodology is a systematic review of how these technologies are integrated to enhance agricultural operations. The paper's key outcome is the conclusion that these advancements are crucial for **maximizing yields and minimizing waste** while simultaneously promoting sustainable farming practices. They propose that future work must address the challenges of data security, network connectivity, and the scalability of these advanced farming solutions.

VI. IMPLEMENTATION INSIGHTS

- **High Initial Investment:** Cost of sensors, gateways, and infrastructure.
- **Technical Expertise:** Requires knowledge of electronics, networking, and software.
- **Connectivity:** Reliable internet/cellular coverage is necessary in rural areas.
- **Data Security:** Protecting farm data from unauthorized access.

VI. CONCLUSION AND FUTURE WORK

IoT-based smart precision farming represents a transformative approach to agriculture, enabling sustainability and efficiency through continuous monitoring and automated control. By leveraging low-cost sensors, robust microcontrollers, and cloud analytics, farmers can make informed decisions that boost productivity and conserve resources. Future work should focus on:

- Developing more cost-effective and durable sensors.
- Enhancing predictive models with AI for greater accuracy.
- Integrating blockchain technology for supply chain transparency from farm to table.

VII. REFERENCES

[1] G. Saha, F. Shahrin, F. H. Khan, M. M. Meshkat, and A. A. M. Azad, "Smart IoT-driven precision agriculture: Land mapping, crop prediction, and irrigation system," *PLOS ONE*, vol. 20, no. 3, p. e0319268, Mar. 2025.

[2] X. Liu, Z. Zhao, and A. Rezaeipanah, "Intelligent and automatic irrigation system based on internet of things using fuzzy control technology," *Sci. Rep.*, vol. 15, p. 14577, 2025.

[3] B. B. Monchusi, A. T. Kgopa, and T. I. Mokwana, "Integrating IoT and AI for Precision Agriculture: Enhancing Water Management and Crop Monitoring in Small-Scale Farms," in *2024 Int. Conf. Intell. Innov. Comput. Appl. (ICONIC)*, 2024.

[4] M. Padhiary, A. Kumar, and L. N. Sethi, "Emerging technologies for smart and sustainable precision agriculture," *Discov. Robot.*, vol. 1, p. 6, 2025.

[5] K. Sharma and S. K. Shivandu, "Integrating artificial intelligence and Internet of Things (IoT) for enhanced crop monitoring and management in precision agriculture," *Sens. Int.*, vol. 5, p. 100292, 2024.

[6] R. Sahu and P. Tripathi, "An intelligent framework for monitoring and irrigation prediction for precision agriculture," Iran J. Comput. Sci., May 2025.

[7] S. Gupta, S. Chowdhury, R. Govindaraj, K. T. T. Ameshof, S. Shangdiar, T. Kadhila, and S. Iikela, "Smart agriculture using IoT for automated irrigation, water and energy efficiency," Smart Agric. Technol., vol. 12, p. 101081, 2025.

[8] H. Shahab, M. Naeem, M. Iqbal, M. Aqeel, and S. S. Ullah, "IoT-driven smart agricultural technology for real-time soil and crop optimization," Smart Agric. Technol., vol. 10, p. 100847, 2025.

[9] S. Kaushik and K. Singh, "AI-Driven Smart Irrigation and Resource Optimization for Sustainable Precision Agriculture," J. Sci. Innov. Adv. Res. (JSIAR), vol. 1, no. 2, May 2025.

[10] M. R. Al Mamun, A. K. Ahmed, S. M. Upoma, M. M. Haque, and M. Ashik-E-Rabbani, "IoT-enabled solar-powered smart irrigation for precision agriculture," Smart Agric. Technol., vol. 10, p. 100773, 2025.

[11] N. P. More, V. Venkataramanan, M. O. Kumar, M. S. Padaya, and F. Solanki, "IoT-Based Precision Farming Robot for Agricultural Automation," Int. Res. J. Multidiscip. Scope, vol. 6, no. 1, pp. 819-832, 2025.

[12] M. S. Sharafat et al., "An IoT-enabled AI system for real-time crop prediction using soil and weather data in precision agriculture," Smart Agric. Technol., vol. 12, p. 101263, 2025.

[13] A. Morchid et al., "IoT-enabled smart agriculture for improving water management: A smart irrigation control using embedded systems and Server-Sent Events," Sci. Afr., vol. 27, p. e02527, 2025.

[14] D. E. Elshikha et al., "Smart Irrigation Solutions for Today's Farms," The University of Arizona Cooperative Extension, Jan. 2025.

[15] P. Sadotra et al., "Integrating Artificial Intelligence & IoT for Precision Farming: Advancing Agriculture 4.0 Solutions," Int. J. Human Comput. Intell., vol. 4, no. 4, p. 521, 2025.

Acknowledgment

The authors thank the faculty and staff of Amruta Institute of Engineering and Management Sciences, Bidadi for their support and guidance.