

Internet of Things (IoT) Enabled Intelligent Farming for Sustainable Agriculture

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Abstract

Internet of Things (IoT) enabled intelligent farming is revolutionizing agriculture by integrating sensors, data analytics, automation to optimize crop yields, reduce waste, and promote sustainability. By providing real-time insights into soil health, weather conditions, irrigation needs, and crop growth, IoT technologies enable farmers to make precise, data-driven decisions, replacing traditional guesswork with actionable intelligence. Applications such as precision farming, smart greenhouses, and livestock monitoring not only improve productivity but also conserve vital resources like water, energy, and fertilizers. These advancements lead to increased crop yields, improved food quality, cost savings, and a reduced environmental footprint. However, challenges such as high initial investment, limited rural connectivity, and data security concerns continue to hinder widespread adoption. Overcoming these barriers is crucial to fully harnessing the potential of IoT in agriculture. This paper addresses these issues, explores the hardware requirements and the potential of IoT-enabled intelligent farming to revolutionize agriculture and promote a more efficient and sustainable future.

Keywords: Internet of Things, Intelligent Farming, Data Driven Decisions, Precision Farming, Sensor, Sustainable Agriculture.

1. Introduction

Agriculture, formerly the backbone of human society, is currently being transformed digitally via the Internet of Things (IoT). Conventional farming, which in the past relied on human labor and responsive decision-making, is increasingly being disintermediated by intelligent systems to facilitate real-time surveillance, predictive analytics, and autonomous control. IoT facilitates interconnecting networks of sensors, microcontrollers, and cloud platforms that enable farmers to maximize resources, maximize productivity, and transition towards sustainable methods. IoT use in agriculture—commonly known as precision farming—embraces monitoring soil moisture, automated irrigation, crop monitoring using drones, livestock tracking, and greenhouse automation (Hussein, 2019) (Patel, Joshi, & Ravikumar, 2020). These technologies have proved to have considerable advantages, including

lowering water usage, enhancing yield prediction, and reducing wastage of inputs. Cloud platforms and mobile dashboards also enable farmers to make more informed decisions with actionable insights, making decision-making more data driven. Although these advancements have occurred, scalability, interoperability, and access present challenges. Costly deployments, rural connectivity problems, and low farmer awareness impede mass adoption. In addition, energy efficiency, data protection, and integrating systems remain urgent issues. Overcoming these constraints is essential to make IoT-based solutions feasible, accessible, and sustainable. This paper addresses these issues, explores the hardware requirements and the potential of IoT-enabled intelligent farming to revolutionize agriculture and promote a more efficient and sustainable future [1].

2. Background Study

Agriculture, the backbone of many economies and the primary source of food and raw materials, is experiencing a paradigm shift with the integration of Internet of Things (IoT) technologies. Traditional farming practices, which largely depend on manual labor and reactive decision-making, are increasingly being replaced by intelligent systems capable of real-time monitoring, predictive analytics, and automated control. This transformation is driven by the urgent need to address global challenges such as climate change, water scarcity, soil degradation, unpredictable weather conditions, and the rising demand for food due to rapid population growth. IoT-enabled intelligent farming introduces a network of interconnected devices, sensors, and platforms that collectively enhance the efficiency, productivity, and sustainability of agricultural operations. At the heart of this technological shift are hardware components that function as the sensory and operational units of the system. Soil moisture sensors guide precise irrigation schedules, while temperature and humidity sensors track microclimatic conditions essential for crop growth. Light sensors (LDRs) monitor sunlight exposure, and nutrients as well as pH sensors provide real-time insights into soil fertility and health. These inputs enable farmers to adopt precision agriculture practices, minimizing wastage of water, fertilizers, and pesticides. Microcontrollers such as Arduino UNO and NodeMCU (ESP8266) serve as processing units, integrating data from sensors and coordinating responses through actuators such as water pumps, relay modules, and automated valves. Emerging tools like drones and AI-enabled cameras further support aerial surveillance, crop health assessment, and terrain mapping, while GPS and RFID modules simplify livestock tracking and inventory management. Solar-powered IoT devices are increasingly employed to ensure energy efficiency and sustainability in remote or resource-limited environments. In parallel, software components form the digital backbone of intelligent farming. The Arduino Integrated Development Environment (IDE) allows programming and integration of various hardware modules, supported by specialized

libraries (e.g., DHT.h for temperature and humidity, LiquidCrystal.h for LCD interfaces, ESP8266WiFi.h for connectivity). For remote data exchange, IoT platforms leverage protocols such as MQTT and HTTP, enabling seamless connectivity with cloud services like ThingSpeak, Blynk, AWS IoT, and Azure IoT Hub. User-friendly visualization tools, including Node-RED dashboards and MIT App Inventor-based mobile applications, allow farmers to monitor conditions and control devices in real time. Furthermore, Arduino Cloud and browser-based editors simplify device management and data analytics without requiring complex installations (Ardiansah, Bafdal, Suryadi, & Bono, 2020). Beyond monitoring and control, IoT-enabled systems are increasingly integrated with advanced technologies such as Artificial Intelligence (AI), Machine Learning (ML), and Big Data analytics. These tools support predictive modeling of weather patterns, early detection of crop diseases, and decision-making for optimized resource allocation. For instance, predictive irrigation systems can estimate water requirements based on soil data and weather forecasts, while AI-driven crop health analysis can alert farmers to potential infestations before they spread widely. Despite its immense potential, IoT in agriculture also faces challenges including high deployment costs, connectivity issues in rural areas, cybersecurity threats, and the need for technical skills among farmers. Nevertheless, ongoing research and innovation continue to reduce these barriers, making intelligent farming a viable pathway toward sustainable agriculture. Thus, IoT-enabled intelligent farming represents a transformative approach to modern agriculture by integrating hardware, software, and data-driven decision-making. This digital ecosystem not only enhances productivity and efficiency but also ensures environmental sustainability, addressing the critical balance between meeting global food demands and conserving natural resources [2].

3. Key Applications

The integration of Internet of Things (IoT) technologies in agriculture has opened new avenues for enhancing efficiency, productivity, and sustainability. One of the primary application areas

is precision irrigation, where soil moisture sensors, weather data, and automated water delivery systems enable optimal water usage. By applying water only when and where it is needed, farmers can conserve resources, reduce costs, and improve crop yield (Dhanaraju et al., 2022). Another significant area is crop monitoring and health management. IoT-enabled sensors, drones, and cameras capture real-time data on plant growth, soil nutrients, temperature, humidity, and light intensity. This data can be analyzed using machine learning algorithms to detect early signs of diseases, pest infestations, or nutrient deficiencies, enabling timely interventions and reducing crop losses (Friha et al., 2021). Greenhouse automation is also an important application, where IoT devices control environmental conditions such as temperature, ventilation, and humidity. Automated systems optimize growing conditions for high-value crops, improve resource efficiency, and minimize human labor requirements. Livestock management benefits from IoT through GPS tracking, RFID tagging, and wearable sensors that monitor animal health, behavior, and location. These systems improve herd management, prevent disease outbreaks, and enhance productivity. Additionally, farm management and decision support systems integrate IoT data into cloud-based dashboards, providing actionable insights for planting schedules, fertilizer application, yield prediction, and market planning. This digital approach enhances decision-making, reduces operational risks, and promotes sustainable agricultural practices. Collectively, these applications demonstrate that IoT-enabled intelligent farming is a transformative tool for achieving sustainable agriculture, addressing resource constraints, and meeting the growing global demand for food while minimizing environmental impact [3].

4. Benefits of Intelligent Farming

The integration of the Internet of Things (IoT) in agriculture has transformed traditional farming into a data-driven, intelligent system that improves productivity, efficiency, and sustainability. From real-time monitoring to smart irrigation and automated operations, IoT technologies have become essential tools for modern agricultural practices. One

of the most valuable benefits is the increase in crop yields. By leveraging real-time data from IoT sensors, farmers can make precise decisions regarding irrigation, fertilization, and pest control. For example, in 2023, the Indian startup “Fasal” reported up to a 30% rise in mango yields through IoT-based environmental monitoring (TDK Ventures, 2023). Precision farming techniques, validated in studies as early as 2018, have shown yield improvements of up to 20%, highlighting the global impact of smart systems (Saha, 2025). Resource conservation is another significant advantage. IoT solutions enable optimal use of water, energy, and fertilizers, promoting sustainable farming. The 2022 “AI4Water” initiative in Telangana, India, is a remarkable example where IoT-controlled irrigation systems reduced water usage by nearly 40% in paddy cultivation (The Pharma Journal, 2022). Likewise, agri-tech firms like ‘DeHaat’ have helped farmers in Bihar and Uttar Pradesh reduce fertilizer costs through soil nutrient monitoring (DeHaat, 2022). Cost efficiency follows naturally from automation and predictive maintenance. Technologies such as satellite-based field monitoring by “Farmonaut” (Farmonaut, 2023) allow early detection of nitrogen deficiency and pest infestations, helping farmers reduce input waste and avoid crop damage. Globally, IoT-based smart irrigation systems contributed to a 30% cut in water usage by 2020, streamlining resources while minimizing expenses (Nsoh & Tchouassi, 2024). Moreover, early problem detection through IoT-enabled alerts plays a crucial role in preventing yield losses. In Punjab, IoT systems helped rice farmers detect and respond to brown plant hopper attacks in 2023, averting widespread crop damage. These innovations support ‘climate-resilient agriculture, enabling farmers to respond rapidly to changing weather conditions and disease outbreaks (Ali, 2025). In controlled environments, smart greenhouses and vertical farms—like those in the Netherlands—leverage IoT sensors and automation to reduce land and water use, producing crops year-round with minimal environmental impact. Editorial coverage from July 2025 emphasized the role of AI-integrated IoT systems and remote sensing in large-

scale crop monitoring and decision-making (Sekin, 2025) (López-Quílez, 2025). IoT-enabled intelligent farming is reshaping agriculture by offering transformative solutions that improve yield, conserve resources, reduce operational costs, and foster sustainable practices. As these technologies evolve, they continue to empower farmers and drive progress toward global food security and eco-friendly. Figure 1 shows the architecture of smart farming implementation [4].

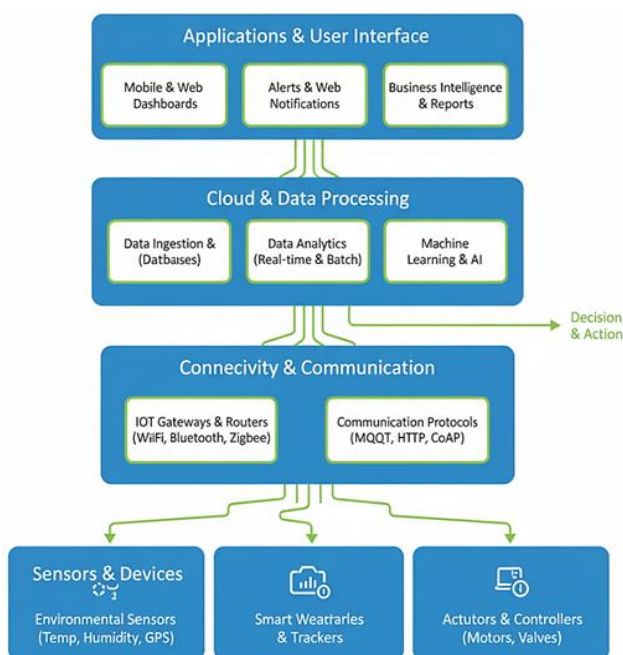


Figure 1 Architecture of Smart Farming

5. Challenges And Solution

5.1. High Initial Costs

- **Challenge:** The cost of sensors, devices, and supporting infrastructure can be unaffordable for small and medium-sized farms.
- **Solution:** Governments and organizations can offer subsidies or low-interest loans to support adoption.
- **Example:** In India, the government provides subsidies through schemes like PM-Kisan to support smart farming tools (Press Information Bureau, 2025[5]).

5.2. Poor Connectivity

- **Challenge:** Many rural farms lack stable internet or mobile connectivity, making real-

time data transmission difficult.

- **Solution:** Invest in rural internet infrastructure such as LPWAN or satellite networks to improve connectivity.
- **Example:** The use of LoRaWAN technology in remote areas of Australia allows farmers to receive sensor data without mobile networks (Digital Matter, 2025) [6].

5.3. Data Management and Security

- **Challenge:** IoT systems generate large volumes of data that are difficult to store, manage, and secure.
- **Solution:** Employ cloud storage with encryption and regular security updates to manage data securely.
- **Example:** Farmers using John Deere's cloud platform benefit from secure and centralized data storage and analytics (John Deere, 2025) [7].

5.4. Lack of Technical Expertise

- **Challenge:** Farmers may not have the skills needed to operate and maintain IoT systems.
- **Solution:** Provide training programs and on-field support to educate farmers on using these tools.
- **Example:** Agritech startups like DeHaat in India conduct workshops to train farmers on digital farming tools (The Startup Spectrum, 2025; AgRevolution, n.d.) [8 - 18].

5.5. Interoperability Issues

- **Challenge:** Different IoT devices often use different standards and are not compatible with one another.
- **Solution:** Promote standardized protocols and open platforms to allow seamless integration.

Conclusion

IoT-enabled intelligent farming represents a transformative shift in the agricultural sector by integrating advanced technologies with traditional farming practices. This study highlights how the use of IoT devices such as sensors for precision farming, greenhouse automation, and livestock monitoring can significantly enhance productivity, resource efficiency, and operational control. Despite the considerable benefits—like increased crop yields,

better resource management, and cost savings, there are notable challenges such as high initial investment, rural connectivity limitations, and data security concerns. However, with ongoing advancements in technology, growing government support, and improved digital infrastructure, these barriers can be gradually overcome. Looking ahead, the future of intelligent farming is promising, with potential developments in AI integration, drone-based monitoring, and data-driven decision-making. Embracing IoT in agriculture not only ensures sustainable farming but also addresses global challenges related to food security and environmental conservation

References

- [1]. Hussein, A. H. (2019). Internet of Things (IoT): Research challenges and future applications. *International Journal of Advanced Computer Science and Applications*, 10(6). <https://doi.org/10.14569/IJACSA.2019.0100611>
- [2]. Patel, D., Joshi, S. L., & Ravikumar, V. (2020). Agriculture monitoring system using IoT—A survey. In *Advances in Intelligent Systems and Computing* (Vol. 1080, pp. 591–600). Springer. https://doi.org/10.1007/978-981-15-0751-9_59
- [3]. Ardiansah, I., Bafdal, N., Suryadi, E., & Bono, A. (2020). Greenhouse monitoring and automation using Arduino: A review on precision farming and Internet of Things (IoT). *International Journal on Advanced Science, Engineering and Information Technology*, 10(2), 708–713. <https://doi.org/10.18517/ijaseit.10.2.7600>
- [4]. Dhanaraju, M., Chenniappan, P., Ramalingam, K., Pazhanivelan, S., & Kaliaperumal, R. (2022). Smart farming: Internet of Things (IoT)-based sustainable agriculture. *Agronomy*, 12(10), 1745. <https://doi.org/10.3390/agronomy12101745>
- [5]. Friha, N., Ben Ayed, H., & Kammoun, F. (2021). Machine learning-based early detection of crop diseases and pests: A review. *Computers and Electronics in Agriculture*, 184, 106070. <https://doi.org/10.1016/j.compag.2021.106070>
- [6]. TDK Ventures. (2023). Why we invested in Fasal. TDK Ventures. <https://tdk-ventures.com/news/insights/why-we-invested-in-fasal/>
- [7]. Saha, S. (2025). Precision agriculture for improving crop yield predictions: A literature review. *Frontiers in Agronomy*. <https://www.frontiersin.org/journals/agronomy/articles/10.3389/fagro.2025.1566201/full>
- [8]. The Pharma Journal. (2022). AI4Water initiative in Telangana: Leveraging IoT for water-efficient paddy cultivation. <https://www.thepharmajournal.com/archives/2022/vol11issue5S/PartE/S-11-2-108-942.pdf>
- [9]. DeHaat. (2022). DeHaat: Empowering farmers through soil testing and advisory services. <https://www.scribd.com/document/589916917/DeHaat>
- [10]. Farmonaut. (2023). Farmonaut: Satellite-based crop health monitoring. <https://farmonaut.com/>
- [11]. Nsoh, B., & Tchouassi, G. (2024). Internet of Things-based automated solutions utilizing machine learning for smart irrigation systems. *Sensors*, 24(23), 7480. <https://doi.org/10.3390/s24237480>
- [12]. Sekin, F. (2025, June 13). Smart greenhouses: Technology for modern agriculture. WINS Solutions. Retrieved from <https://www.winssolutions.org/smart-greenhouses-modern-agriculture/>
- [13]. López-Quílez, A. (2025, March 7). AI, IoT and remote sensing in precision agriculture. *Applied Sciences*, 15(6), 2890. <https://doi.org/10.3390/app15062890>
- [14]. Press Information Bureau. (2025, August 1). 20th instalment of PM-KISAN to be released on 2nd August 2025. Government of India. Retrieved from <https://www.pib.gov.in/PressNoteDetails.aspx?ModuleId=3&NoteId=154960>
- [15]. Digital Matter. (2025). Improving farm safety and management with LoRaWAN and

- Farmdeck. Retrieved from <https://www.digitalmatter.com/case-studies/improving-farm-safety-and-management-with-lorawan-and-farmdeck>
- [16]. John Deere. (2025). Operations Center™: Precision agriculture technology and data management. Retrieved from <https://www.deere.com/en/technology-products/precision-ag-technology/>
- [17]. John Deere. (2025). Data services and privacy. Retrieved from <https://www.deere.com/en/privacy-and-data/data-services/index.html>
- [18]. The Startup Spectrum. (2025, March 12). DeHaat acquires AgriCentral to strengthen digital services for farmers. Retrieved from <https://thestartupspectrum.com/dehaat-acquires-agricentral-to-strengthen-digital-services-for-farmers/>