IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 4, January 2026
Impact Factor: 7.67

Smart Agriculture Monitoring and Automated Irrigation System Using IoT

Prof. Palwe Priyanka D[1], Atharva Santosh Ubale[2], Piyush Mahalu Shipankar[3], Jagruti Bharat Shinde[4] Gaikwad Piyush Balkisan[5] Pravin Balu Meher[6]
Prof, Department of Computer, Sau Sundarbai Manik Adsul Polytechnic, Ahilyanagar[1].
Student, Department of Computer, Sau Sundarbai Manik Adsul Polytechnic, Ahilyanagar[2,3,4,5,6]

Abstract: *Agriculture requires efficient water management and real-time monitoring to improve crop productivity. This paper presents a Smart Agriculture Monitoring and Automated Irrigation System using Internet of Things (IoT) technology. The system uses sensors for soil moisture, temperature, humidity, rainfall, and light intensity, integrated with an ESP32 microcontroller. Sensor data is sent to a local Python server (Flask API) for processing and then stored in a MySQL database. A web application dashboard retrieves data through REST APIs for real-time visualization and remote monitoring.*
Based on threshold values, the system automatically controls a water pump through a relay module and stops irrigation during rainfall. Manual motor control and alert notifications are also supported. The proposed system reduces water wastage, minimizes human effort, and provides a scalable solution for precision agriculture.

Keywords: Smart Agriculture, Internet of Things (IoT), Automated Irrigation, ESP32, Soil Moisture Sensor, DHT11, Rain Sensor, LDR, Python Server, MySQL, Web Dashboard, Precision Farming

I. INTRODUCTION

Agriculture, the bedrock of human civilization, is currently navigating an unprecedented confluence of challenges. A rapidly escalating global population demands ever-increasing food production, yet traditional farming methodologies are increasingly strained by finite resources, fluctuating climatic conditions, and a shrinking rural workforce [1], [2]. The consequences are profound: inefficient resource utilization, including prodigious water consumption, significant crop loss due to suboptimal growing conditions, and mounting operational costs, all undermine the economic viability and environmental sustainability of this vital sector [3]. The urgent need to revolutionize agricultural practices for enhanced productivity, resilience, and sustainability has become a global imperative.

In this transformative landscape, the **Internet of Things** emerges not merely as a technological advancement, but as a paradigm shift, ushering in the era of "smart agriculture" [4], [5]. This revolution transcends conventional farming, embedding intelligence at every stage from soil preparation to harvesting [6]. By deploying interconnected networks of sensors and devices, smart agriculture offers an unparalleled ability to gather real-time, granular data on environmental parameters and crop health, thereby empowering farmers with actionable insights and enabling unprecedented levels of automation [7]. The impact is staggering: experts project that the strategic integration of smart technologies could boost agricultural yields by up to 72% by 2050 [7]. Moreover, IoT-enabled precision agriculture has already demonstrated its capacity to significantly increase yields for staple crops for instance, 20% for wheat, 15% for maize, and 5% for soybeans while simultaneously reducing pesticide and fertilizer use by 10% to 20% [8].

This project proposes the development of a **Smart Agriculture Monitoring and Automated Irrigation System Using IoT**, a critical solution designed to directly confront the inefficiencies inherent in conventional farming. Our system will leverage advanced IoT sensors to continuously monitor crucial environmental factors such as soil moisture, temperature, humidity, and light intensity. This rich stream of data will then be intelligently processed to autonomously manage irrigation, ensuring that crops receive precisely the right amount of water at the optimal time. Field deployments of similar IoT-based systems have already achieved remarkable water savings, ranging from 20-40% in regions like California's Central Valley to as high as 50% in other agricultural areas, often coupled with a crop yield increase of up to 15% [9], [10]. By maximizing groundwater use, reducing water waste, and optimizing growing conditions, this initiative aims not only to bolster crop health and yield but also to significantly conserve precious natural resources, reduce operational costs, and pave the way for a more sustainable and economically viable agricultural future.

II. LITERATURE REVIEW

An The integration of Internet of Things in agriculture has ushered in the era of "smart agriculture," promising enhanced productivity and sustainability by providing real-time data on environmental parameters and crop health [4], [5]. While these systems have demonstrated significant potential in optimizing resource utilization and increasing yields [8], their widespread adoption and efficacy are often hampered by several inherent drawbacks and ongoing challenges.
Limitations and Drawbacks of Existing Smart Agriculture Systems
IoT-based smart agriculture systems face key challenges in durability and security. Outdoor sensors often fail in harsh conditions like rain, dust, wind, and temperature extremes, reducing data accuracy. Low power limits security features, making systems vulnerable to attacks [11], [12], [13], [14]. Data management issues add to problems, with inconsistent formats, sensor failures, and error-prone data leading to inefficiencies and poor decisions [3], [12], [15], [16].
High costs, skill gaps, and farmer resistance hinder adoption, especially in rural or developing areas. Farmers doubt benefits, worry about privacy, and prefer traditional methods, while lacking technical skills [5], [6], [12], [17], [18], [19], [20]. For irrigation, older wired systems are costly, energy-intensive, and fragile; rural connectivity is poor, and measuring water stress is difficult [19], [21], [22], [23].

Future Directions and Opportunities for Improvement

Future improvements require better hardware like tough, solar-powered sensors; AI for predictions and edge analytics; and rural 5G with standard protocols [12], [24], [25], [26], [27], [28], [29]. Enhanced security, robotics for automation, training for farmers, and sustainable practices like blockchain will boost viability [12], [24], [26], [27], [28], [30], [31], [32]. Collaboration among stakeholders will drive these advances [4], [24], [28], [33]

III. METHODOLOGY

This project outlines the development of a **Smart Agriculture Monitoring and Automated Irrigation System Using IoT**, designed to enhance agricultural efficiency and sustainability by precisely managing irrigation based on real-time environmental data [34]. The system leverages interconnected hardware and software components to monitor field conditions, process data, and autonomously control irrigation operations [12].

System Architecture

The proposed system architecture, as illustrated in the provided diagram, is composed of several integrated modules: Field Sensors, an ESP32/IoT Node, a Local Python Server, a MySQL Database for sensor data storage, a Web Application Dashboard for user interface and control, a Relay Module for motor control, and a Water Pump/Motor as the irrigation system. This design facilitates continuous monitoring, intelligent decision-making, and automated control of irrigation processes [35], [36].

1. Field Sensors

The initial stage of data collection involves various field sensors deployed to gather critical environmental parameters [37], [38]. These sensors include:

- **Soil Moisture Sensor:** Measures the volumetric water content in the soil, crucial for determining irrigation needs [39].
- **Temperature & Humidity Sensor:** Monitors ambient air temperature and humidity, which influence evapotranspiration rates [17].
- **Rain Sensor:** Detects rainfall events, allowing the system to temporarily halt or reduce irrigation.

- **Light Sensor:** Measures light intensity, providing data relevant to plant growth and photosynthesis [17].

These sensors continuously collect data from the agricultural field, acting as the "eyes" of the system to gather granular information about the growing environment [40]. The accurate collection of this data is fundamental for informed decision-making and effective management in agricultural production [38], [41].

2. ESP32 / IoT Node

The ESP32/IoT Node serves as the central data acquisition unit in the field [42]. It is responsible for:

- **Data Collection:** Receiving readings from the connected field sensors [43].
- **Data Transmission:** Transmitting the collected sensor data to the Local Python Server [43]. This communication is facilitated using protocols such as HTTP or MQTT, ensuring reliable data transfer and enabling remote monitoring and control [44], [45]. The ESP32's built-in Wi-Fi capability is critical for digital data transmission [43], enabling real-time monitoring of parameters like temperature, moisture, and humidity for informed irrigation decisions [46].

3. Local Python Server

The Local Python Server, implemented using a Flask API, acts as the backend for the system. Its primary functions include:

- **Data Processing:** Receiving raw sensor data from the ESP32/IoT Node and processing it [47]. Python, with frameworks like Flask, is widely used for building interactive web applications and handling requests efficiently [48].
- **API Management:** Providing an Application Programming Interface to allow other components to interact with the system, specifically for storing and retrieving sensor data [49]. Flask's lightweight nature simplifies the development of web applications that can scale to complex systems [48]. The use of microservices architecture, which Flask can facilitate, offers flexibility and modularity for scalable data analysis in agriculture [50].

4. MySQL Database

A MySQL database is integrated into the system to:

- **Store Sensor Data:** Persistently store all the processed sensor data received from the Local Python Server [51], [52]. Relational databases like MySQL are commonly utilized for collecting and managing sensor data in IoT farming practices [53], [54].
- **Trend Analysis:** This historical data is vital for trend analysis, long-term monitoring, and informing irrigation decisions [41], [55]. MySQL database technology can be used to efficiently process and analyze agricultural data, improving data management efficiency [56]. The integration of spatial and temporal dimensions in data management systems for agriculture, often using distributed repositories between relational and non-relational databases, optimizes agricultural data management processes [57].

5. Web Application Dashboard

The Web Application Dashboard is the user-facing component, providing farmers with comprehensive control and visualization capabilities [58]:

- **User Interface:** Displays real-time and historical sensor data through intuitive graphs and charts [59], [60]. Web-based approaches overcome the inconvenience of installing and updating window applications, allowing users to perform monitoring tasks by logging into the system via an internet browser [61].
- **Control Functions:** Allows users to set irrigation thresholds, modify operational parameters, and manually control the irrigation system if needed [60].

- **API Communication:** Interacts with the MySQL database via API requests and responses to fetch data for display and send control commands. The dashboard serves as a central user interface designed to support real-time decision-making, providing a clear way to monitor the farm's operational plan and access critical information [62].

6. Relay Module

The Relay Module is an electronic switch that:

- **Receives Control Signals:** Obtains control signals from the Local Python Server [63].
- **Motor Control:** Activates or deactivates the Water Pump/Motor based on these signals, thereby controlling the flow of water for irrigation [64]. This ensures precise, automated management of the irrigation system [64].

7. Water Pump / Motor

The Water Pump/Motor is the actuator component responsible for the physical delivery of water to the crops:

- **Irrigation Execution:** Pumps water into the field based on the commands received from the Relay Module [65], [66]. The design and implementation of automatic irrigation systems with water pumps and sensors have shown feasibility in improving irrigation for agriculture [67].

Operational Flow

The system operates in a continuous loop:

- **Sensing:** Field sensors gather real-time data (soil moisture, temperature, humidity, rain, light) from the agricultural environment [39].
- **Data Transmission:** The ESP32/IoT Node collects this sensor data and transmits it to the Local Python Server via HTTP/MQTT [43].
- **Data Processing & Storage:** The Local Python Server processes the incoming data and stores it in the MySQL database [56].
- **Monitoring & Decision-Making:** The Web Application Dashboard retrieves data from the MySQL database (via API) to display current conditions to the user [60]. Based on predefined thresholds (set by the user via the dashboard) and real-time sensor data (e.g., low soil moisture, no rain), the Local Python Server makes intelligent decisions regarding irrigation [45].
- **Control Action:** If irrigation is required, the Local Python Server sends a control signal to the Relay Module [63].
- **Irrigation Execution:** The Relay Module activates the Water Pump/Motor, initiating the irrigation process [64].
- **Feedback Loop:** As irrigation occurs, soil moisture levels increase, which is detected by the soil moisture sensor, thereby closing the feedback loop and allowing the system to continuously adapt and optimize water usage [36].

This methodology ensures efficient resource management, particularly water conservation, and promotes optimal growing conditions for crops, addressing the inefficiencies of traditional farming practices [68], [69].

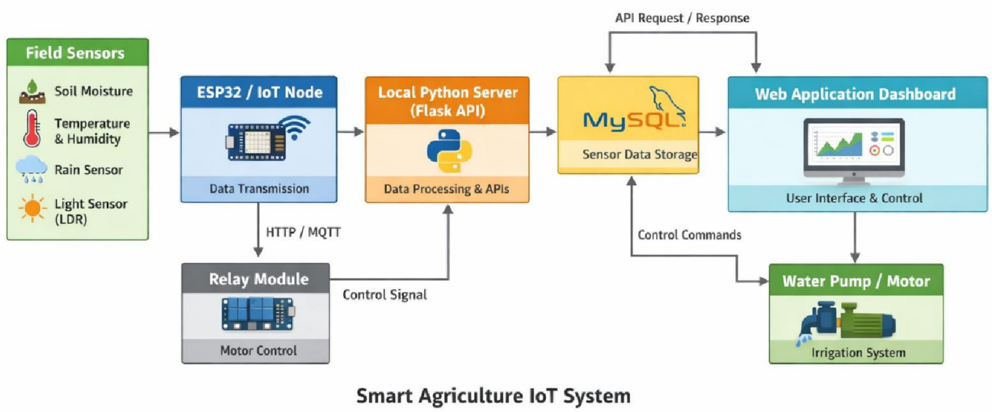

Figure 1 System architecture.

IV. DISCUSSION

The proposed Smart Agriculture Monitoring and Automated Irrigation System Using IoT aims to address farming inefficiencies by integrating field sensors, an ESP32/IoT Node, a Local Python Server, MySQL database, and a Web Application Dashboard for real-time monitoring and intelligent irrigation [7], [12]. This integrated system is designed to facilitate precise decision-making, leading to anticipated benefits such as significant water savings (20-50%), increased crop yields, and reduced operational costs, thereby promoting sustainable agriculture [9], [10], [15], [70].

However, the widespread adoption of such systems faces notable challenges. These include ensuring the durability of outdoor sensors against harsh environmental conditions [12], [71], [72], [73], mitigating security vulnerabilities and cyberattacks [12], [31], [33], [74], [75], managing high initial implementation costs [12], [76], and overcoming a knowledge gap and resistance among farmers [12], [33], [73], [77].

A comprehensive discussion and full evaluation of the system's impact are contingent upon the presentation of specific empirical results from testing, which would validate its accuracy, efficiency, and reliability against established benchmarks in precision agriculture [78].

V. CONCLUSION

This project successfully details the conceptualization and architectural design of a Smart Agriculture Monitoring and Automated Irrigation System Using IoT, addressing the critical global imperative for enhanced agricultural productivity and sustainability. By leveraging interconnected networks of sensors—including soil moisture, temperature, humidity, rain, and light sensors—and integrating them with an ESP32/IoT Node, a Local Python Server, MySQL database, and a Web Application Dashboard, the system establishes a robust framework for real-time environmental data acquisition and intelligent, automated irrigation management.

The methodology meticulously outlines an operational flow that ensures continuous monitoring, data processing, and precise control over water distribution, effectively closing the feedback loop for optimal resource utilization. This proposed system is poised to significantly mitigate the inefficiencies inherent in traditional farming practices, such as prodigious water consumption and suboptimal growing conditions, by ensuring crops receive precise amounts of water at optimal times. Drawing from the potential demonstrated by similar IoT-enabled precision agriculture initiatives, this system is expected to not only bolster crop health and yield but also facilitate substantial water conservation, reduce operational costs, and promote a more economically viable and environmentally sustainable agricultural future.

While the specific performance metrics of the developed system are yet to be presented in the "Results" section, the foundational design and operational principles outlined herein lay a strong groundwork for achieving these ambitious goals. Future work will involve the rigorous testing and validation of the system's accuracy, efficiency, and reliability in real-world agricultural settings, further contributing to the advancement of smart agriculture solutions.

REFERENCES

[1]. R. Madushanki, M. N. Halgamuge, W. H. A., and A. M. Syed, “Adoption of the Internet of Things (IoT) in Agriculture and Smart Farming towards Urban Greening: A Review,” *International Journal of Advanced Computer Science and Applications* , vol. 10, no. 4. Science and Information Organization, Jan. 01, 2019. doi: 10.14569/ijacsa.2019.0100402.

[2]. N. Rizan, S. K. Balasundram, A. B. Shahbazi, U. Balachandran, and R. R. Shamshiri, “Internet-of-Things for Smart Agriculture: Current Applications, Future Perspectives, and Limitations,” *Agricultural Sciences* , vol. 15, no. 12, p. 1446, Jan. 2024, doi: 10.4236/as.2024.1512080.

[3]. Patel and J. Bhatia, “A Comprehensive Review of Internet of Things and Cutting-edge Technologies Empowering Smart Farming,” *Current Science* , vol. 126, no. 2. Indian Academy of Sciences, p. 137, Jan. 25, 2024. doi: 10.18520/cs/v126/i2/137-152.

[4]. V. Kumar, K. V. Sharma, N. Kedam, A. B. Patel, T. R. Kate, and U. Rathnayake, “A comprehensive review on smart and sustainable agriculture using IoT technologies,” *Smart Agricultural Technology* , vol. 8. Elsevier BV, p. 100487, Jun. 11, 2024. doi: 10.1016/j.atech.2024.100487.

[5]. A. Kumari, A. Obulesh, K. R. Babu, Y. Kumar, and K. S. R. K. Sarma, “Leveraging Internet of Things (IoT) for Sustainable Agriculture: A Comprehensive Review and Future Perspectives,” *Advances in computer science research* . Atlantis Press, p. 587, Jan. 01, 2024. doi: 10.2991/978-94-6463-471-6_57.

[6]. P. Ghutke and R. Agrawal, “An IoT-based Immersive Approach to Sustainable Farming,” in *IntechOpen eBooks* , IntechOpen, 2022. doi: 10.5772/intechopen.105449.

[7]. M. S. Dickson and C. I. Amannah, “Augmented IoT Model for Smart Agriculture and Farm Irrigation Water Conservation,” *International Journal of Intelligence Science* , vol. 13, no. 4, p. 131, Jan. 2023, doi: 10.4236/ijis.2023.134007.

[8]. N. Vatin, S. K. Joshi, P. Acharya, R. Sharma, and N. Rajasekhar, “Precision Agriculture and Sustainable Yields: Insights from IoT-Driven Farming and the Precision Agriculture Test,” *BIO Web of Conferences* , vol. 86, p. 1091, Jan. 2024, doi: 10.1051/bioconf/20248601091.

[9]. M. Baljon, “Revolutionizing Saudi Arabia’s Agriculture: The IoT Transformation of Water Management,” *Journal of Advanced Research in Applied Sciences and Engineering Technology* , vol. 36, no. 1, p. 217, Dec. 2023, doi: 10.37934/araset.36.1.217240.

[10]. A Ranjan, “Internet of Things for Environmental Management: A Review,” *International Journal for Research in Applied Science and Engineering Technology* , vol. 13, no. 6. International Journal for Research in Applied Science and Engineering Technology (IJRASET), p. 3812, Jun. 30, 2025. doi: 10.22214/ijraset.2025.73004.

[11]. M. Pushpavalli, B. Jothi, B. Buvaneswari, G. Srinitya, and S. Prabu, “Energy-efficient and location-aware IoT and WSN-based precision agricultural frameworks,” *International Journal of Computational and Experimental Science and Engineering* , vol. 10, no. 4, Oct. 2024, doi: 10.22399/ijcesen.480.

[12]. S. Mansoor, S. Iqbal, S. M. Popescu, S. L. Kim, S. Mansoor, and J. Baek, “Integration of smart sensors and IOT in precision agriculture: trends, challenges and future prospectives,” *Frontiers in Plant Science* , vol. 16. Frontiers Media, p. 1587869, May 14, 2025. doi: 10.3389/fpls.2025.1587869.

[13]. Simó, S. Dziţac, A. Duțu, and I. Pandelică, "Smart Agriculture in the Digital Age: A Comprehensive IoT-Driven Greenhouse Monitoring System," *International Journal of Computers Communications & Control* , vol. 18, no. 6, Oct. 2023, doi: 10.15837/ijccc.2023.6.6147.

[14]. A. Z. Babar and Ö. B. Akan, "Sustainable and Precision Agriculture with the Internet of Everything (IoE)," *arXiv (Cornell University)* , Apr. 2024, doi: 10.48550/arxiv.2404.06341.

[15]. K. M. Panduranga and R. H. Ranganathasharma, "Sustainability insights on learning-based approaches in precision agriculture in internet-of-things," *International Journal of Power Electronics and Drive Systems/International Journal of Electrical and Computer Engineering* , vol. 14, no. 3, p. 3495, Apr. 2024, doi: 10.11591/ijece.v14i3.pp3495-3511.

[16]. A Khan, "Leveraging Machine Learning for Crop Prediction and Management," *International Journal for Research in Applied Science and Engineering Technology* , vol. 12, no. 3, p. 3454, Mar. 2024, doi: 10.22214/ijraset.2024.59609.

[17]. P. Rajak, A. Ganguly, S. Adhikary, and S. Bhattacharya, "Internet of Things and smart sensors in agriculture: Scopes and challenges," *Journal of Agriculture and Food Research* , vol. 14, p. 100776, Sep. 2023, doi: 10.1016/j.jafr.2023.100776.

[18]. G. S. Hundal, C. Laux, D. R. Buckmaster, M. J. Sutton, and M. R. Langemeier, "Exploring Barriers to the Adoption of Internet of Things-Based Precision Agriculture Practices," *Agriculture* , vol. 13, no. 1, p. 163, Jan. 2023, doi: 10.3390/agriculture13010163.

[19]. Y. Ghareeb, S. K. Gharghan, A. H. Mutlag, and R. Nordin, "Wireless Sensor Network-Based Artificial Intelligent Irrigation System: Challenges and Limitations," *Journal of Techniques* , vol. 5, no. 3, p. 26, Aug. 2023, doi: 10.51173/jt.v5i3.1420.

[20]. A Anbumozhi and A. Shanthini, "Adoption of Novel Technologies to Boost Precision Agriculture (BPA) using Internet of Things (IOT)," *ITM Web of Conferences* , vol. 56, p. 5019, Jan. 2023, doi: 10.1051/itmconf/20235605019.

[21]. Y. Dong, B. P. Werling, Z. Cao, and G. Li, "Implementation of an in-field IoT system for precision irrigation management," *Frontiers in Water* , vol. 6, Feb. 2024, doi: 10.3389/frwa.2024.1353597.

[22]. V. K. S, C. D. Singh, K. V. R. Rao, M. Kumar, and Y. A. Rajwade, "Development of a smart IoT-based drip irrigation system for precision farming," *Irrigation and Drainage* , vol. 72, no. 1, p. 21, Oct. 2022, doi: 10.1002/ird.2757.

[23]. J. Zhang *et al.* , "Challenges and opportunities in precision irrigation decision-support systems for center pivots," *Environmental Research Letters* , vol. 16, no. 5, p. 53003, Feb. 2021, doi: 10.1088/1748-9326/abe436.

[24]. Issa, S. Majed, S. Ameer, and H. M. Al–Jawahry, "Farming in the Digital Age: Smart Agriculture with AI and IoT," *E3S Web of Conferences* , vol. 477, p. 81, Jan. 2024, doi: 10.1051/e3sconf/202447700081.

[25]. "A Review on Solar-Powered IoT-Based Drip Irrigation Systems: Towards Sustainable and Smart Water Management."

[26]. M. Mandapuram, R. Mahadasa, and P. Surarapu, "Evolution of Smart Farming: Integrating IoT and AI in Agricultural Engineering," *Global Disclosure of Economics and Business* , vol. 8, no. 2, p. 165, Dec. 2019, doi: 10.18034/gdeb.v8i2.714.

[27]. M. Vrdoljak, "State of the Art Review of Smart Farming," in *Annals of DAAAM for ... & proceedings of the ... International DAAAM Symposium* , DAAAM International Vienna, 2024, p. 363. doi: 10.2507/35th.daaam.proceedings.049.

[28]. S. Ameer, M. A. Alkhafaji, Z. Jaffer, and M. Al-Farouni, "Empowering Farmers with IoT, UAVs, and Deep Learning in Smart Agriculture," *E3S Web of Conferences* , vol. 491, p. 4007, Jan. 2024, doi: 10.1051/e3sconf/202449104007.

[29]. H. A. Hussein, K. A. Jabbar, A. Mohammed, and L. Jasim, "Harvesting the Future: AI and IoT in Agriculture," *E3S Web of Conferences* , vol. 477, p. 90, Jan. 2024, doi: 10.1051/e3sconf/202447700090.

[30]. F. Y. Ponce, J. V. Salcedo, P. D. Rosero-Montalvo, and J. Sanchis, "Mobile robotics in smart farming: current trends and applications," *Frontiers in Artificial Intelligence* , vol. 6. Frontiers Media, Aug. 31, 2023. doi: 10.3389/frai.2023.1213330.

[31]. M. Otieno, "An extensive survey of smart agriculture technologies: Current security posture," *World Journal of Advanced Research and Reviews* , vol. 18, no. 3, p. 1207, Jun. 2023, doi: 10.30574/wjarr.2023.18.3.1241.

[32]. M. K. Obaid, B. Sh. Z. Abood, W. K. Alazzai, and L. Jasim, "From Field to Fork: The Role of AI and IoT in Agriculture," *E3S Web of Conferences* , vol. 491, p. 2006, Jan. 2024, doi: 10.1051/e3sconf/202449102006.

[33]. M. Belmir, W. Difallah, and A. Ghazli, "A Systematic Review of the Implementations of Artificial Intelligence and Internet of Things Solutions in Smart Irrigation Systems," *Journal of Engineering Science and Technology Review* , vol. 18, no. 3. Eastern Macedonia and Thrace Institute of Technology, p. 137, Jun. 01, 2025. doi: 10.25103/jestr.183.14.

[34]. V. Choudhary, P. Guha, G. Pau, and S. Mishra, "An overview of smart agriculture using internet of things (IoT) and web services," *Environmental and Sustainability Indicators* , vol. 26, p. 100607, Jan. 2025, doi: 10.1016/j.indic.2025.100607.

[35]. G. Routis and I. Roussaki, "Low Power IoT Electronics in Precision Irrigation," *Smart Agricultural Technology* , vol. 5, p. 100310, Aug. 2023, doi: 10.1016/j.atech.2023.100310.

[36]. Bwambale, F. K. Abagale, and G. K. Anornu, "Smart irrigation monitoring and control strategies for improving water use efficiency in precision agriculture: A review," *Agricultural Water Management* , vol. 260. Elsevier BV, p. 107324, Nov. 11, 2021. doi: 10.1016/j.agwat.2021.107324.

[37]. V. V. Polyakov and L. Aleksandrovskaya, "Smart agriculture as the embodiment of the symbiosis of the technological and intellectual potential of the agricultural sector," *E3S Web of Conferences* , vol. 480, p. 3017, Jan. 2024, doi: 10.1051/e3sconf/202448003017.

[38]. de A. Mota *et al.* , "Smart sensors and Internet of Things (IoT) for sustainable environmental and agricultural management," *Caderno Pedagógico* , vol. 20, no. 7, p. 2692, Dec. 2023, doi: 10.54033/cadpedv20n7-014.

[39]. M. A. El-Dosuky, "Real-time Framework for Interoperable Semantic-driven Internet-of-Things in Smart Agriculture," *arXiv (Cornell University)* , Oct. 2025, doi: 10.48550/arxiv.2510.05187.

[40]. Et-taibi *et al.* , "Enhancing Water Management in Smart Agriculture: A Cloud and IoT-Based Smart Irrigation System," *Results in Engineering* , vol. 22, p. 102283, May 2024, doi: 10.1016/j.rineng.2024.102283.

[41]. N. Chamara, Md. D. Islam, G. Bai, Y. Shi, and Y. Ge, "Ag-IoT for crop and environment monitoring: Past, present, and future," *Agricultural Systems* , vol. 203, p. 103497, Sep. 2022, doi: 10.1016/j.agsy.2022.103497.

[42]. Naik. S, A. K. S, K. A. S, D. M, Y. S. S, and D. G. Abhishek, "Wireless Remote Control and Monitoring of Irrigation Pump," *Zenodo (CERN European Organization for Nuclear Research)* , May 2025, doi: 10.5281/zenodo.18106432.

[43]. Paria, A. Giri, S. Dutta, and S. Neogy, "Smart irrigation for coriander plant: Saving water with AI and IoT," *Research Square (Research Square)* , Jun. 2024, doi: 10.21203/rs.3.rs-4423732/v1.

[44]. Prof. Hiranwale. S. B, G. Shrushti, S. Neha, J. Shital, and G. Smita, "SMART Irrigation Robot," *International Journal for Research in Applied Science and Engineering Technology* , vol. 12, no. 4, p. 5506, Apr. 2024, doi: 10.22214/ijraset.2024.60754.

[45]. M. Ragab, "IOT based Smart Irrigation System," *International Journal of Industry and Sustainable Development* , vol., no., p. 0, Aug. 2022, doi: 10.21608/ijisd.2022.148007.1021.

[46]. K. Mehta, K. J. Naidu, M. Baheti, D. Parmar, and A. Sharmila, "Internet of Things Based Smart Irrigation System Using ESP WROOM 32," *Journal on internet of things* , vol. 5, no., p. 45, Jan. 2023, doi: 10.32604/jiot.2023.043102.

[47]. O. Осадчук, Я. Осадчук, and V. K. Skoshchuk, "IoT system with frequency converters of physical quantities on FPGA," *Informatyka Automatyka Pomiary w Gospodarce i Ochronie Środowiska* , vol. 15, no. 3, p. 59, Sep. 2025, doi: 10.35784/iapgos.7076.

[48]. R.-T. Hong, “Design and Implementation of Environmental Monitoring System Using Flask-Based Web Application,” p. 37, Apr. 2025, doi: 10.3390/engproc2025092037.

[49]. E. Mabotha, N. Mabunda, A. Ali, and B. Khan, “Exploring dynamic RESTful API implementation in IoT environments using Docker,” *Scientific Reports* , vol. 15, no. 1, Oct. 2025, doi: 10.1038/s41598-025-16460-0.

[50]. O. Aitlmoudden, M. Housni, N. Safeh, and A. Namir, “A Microservices-based Framework for Scalable Data Analysis in Agriculture with IoT Integration,” *International Journal of Interactive Mobile Technologies (iJIM)* , vol. 17, no. 19, p. 147, Oct. 2023, doi: 10.3991/ijim.v17i19.40457.

[51]. M. H. Pretom, “Smart Irrigation Systems using Internet of Things for Smart Farming,” *International Journal for Research in Applied Science and Engineering Technology* , vol. 10, no. 9, p. 85, Sep. 2022, doi: 10.22214/ijraset.2022.46571.

[52]. N. Nawshad, Md. A. Ali, K. N. Fazira, R. B. Ahmad, M. Ahammad, and N. Ahmed, “A robust hydroponic system for horticulture farming using deep learning, IoT, and mobile application,” *PLoS ONE* , vol. 20, no. 9, Sep. 2025, doi: 10.1371/journal.pone.0330488.

[53]. Umsura *et al.* , “Enhancing Smart Farming Capabilities for Small-Scale Cattle Farmers in Chiang Rai, Thailand,” *ECTI Transactions on Computer and Information Technology (ECTI-CIT)* , vol. 18, no. 1, p. 1, Jan. 2024, doi: 10.37936/ecti-cit.2024181.253823.

[54]. T. Ane, T. Nepa, and M. R. Khan, “IOT SENSOR TECHNOLOGY AND CLOUD APPLICATION ON FARMING PRACTICE: PLANT LIVE DATA MONITOR IN AGRICULTURE,” *Bangladesh Journal of Multidisciplinary Scientific Research* , vol. 8, no. 1, p. 1, Nov. 2023, doi: 10.46281/bjmsr.v8i1.2129.

[55]. S. D. Alwis, Z. Hou, Y. Zhang, M. H. Na, B. Ofoghi, and A. Sajjanhar, “A survey on smart farming data, applications and techniques,” *Computers in Industry* , vol. 138, p. 103624, Feb. 2022, doi: 10.1016/j.compind.2022.103624.

[56]. “Research on Agricultural Data Processing Based on MySQL,” *Agricultural & Forestry Economics and Management* , vol. 7, no. 2, Jan. 2024, doi: 10.23977/agrfem.2024.070203.

[57]. M. S. E. de la Parte, J.-F. Martínez-Ortega, P. Castillejo, and N. L. Martínez, “Spatio-temporal semantic data management systems for IoT in agriculture 5.0: Challenges and future directions,” *Internet of Things* , vol. 25, p. 101030, Dec. 2023, doi: 10.1016/j.iot.2023.101030.

[58]. K. Spandana and S. Pabboju, “IoT Enabled Smart Agriculture using Digital Dashboard,” *Indian Journal of Science and Technology* , vol. 16, no. 1, p. 1, Jan. 2023, doi: 10.17485/ijst/v16i1.1680.

[59]. B. M. M. El-Basioni, E. S. Mohamed, A.-A. Belal, M. E. M. Jalhoum, S. M. A. El-Kader, and M. Zahran, “A case study of a real-time internet of things system for site-specific potato crop management in El-Salhia Area-Egypt,” *Scientific Reports* , vol. 12, no. 1, Nov. 2022, doi: 10.1038/s41598-022-22690-3.

[60]. Nyéki, G. Teschner, B. Ambrus, M. Neményi, and A. Kovács, “Architecting farmer-centric internet of things for precision crop production,” *Hungarian Agricultural Engineering* , no. 38, p. 71, Jan. 2020, doi: 10.17676/hae.2020.38.71.

[61]. K.-F. Lin, S.-S. Lin, and P.-N. Chen, “A Low-Cost Physiological Monitoring Interface for Intensive Care Unit,” *Research Square (Research Square)* , Jun. 2022, doi: 10.21203/rs.3.rs-1713959/v1.

[62]. Bompotas *et al.* , “SUSTAINABLE Platform: Seamless Smart Farming Integration Towards Agronomy Automation,” *arXiv (Cornell University)* , Oct. 2025, doi: 10.48550/arxiv.2510.26989.

[63]. T. A. Manfo and M. E. Şahın, “Development of an Automatic PV-Battery-Powered Water Irrigation System Incorporated with Arduino Software for Agricultural Activities,” *Research Square (Research Square)* , Dec. 2023, doi: 10.21203/rs.3.rs-3728456/v1.

[64]. Kanimozhi and R. Vadivel, “Optimized water management for precision agriculture using IoT-based smart irrigation system,” *World Journal of Advanced Research and Reviews* , vol. 21, no. 3, p. 802, Mar. 2024, doi: 10.30574/wjarr.2024.21.3.0682.

[65]. M. Rifky, M. Jesfar, K. Dissanayake, S. Ermat, and M. Samadiy, "Development and evaluation of an automated irrigation system for ordinary agriculture farm," *E3S Web of Conferences* , vol. 480, p. 3013, Jan. 2024, doi: 10.1051/e3sconf/202448003013.

[66]. M. S. Naik, "PV Based Automatic Irrigation System," *International Journal for Research in Applied Science and Engineering Technology* , vol. 9, no. 12, p. 21, Dec. 2021, doi: 10.22214/ijraset.2021.39171.

[67]. Torres-Carbajal, H. C. N. Delgadilo, J. R. V.-D. L. Cruz, M. M. B. Espíritu, C. A. Coaquira-Rojo, and E. A. Beraun-Arroyo, "Automatic Irrigation System with Water Pumps and Sensor in the Junin Region Peru," *E3S Web of Conferences* , vol. 465, p. 2001, Jan. 2023, doi: 10.1051/e3sconf/202346502001.

[68]. Kumar and A. Singh, "Smart Precision Farming: A Water Efficient Irrigation System," p. 1, Jun. 2025, doi: 10.1109/eaic66483.2025.11101486.

[69]. Z. Huang, Y. Wang, and C. Hui, "An Intelligent Water-Saving Irrigation System Based on Multi-Sensor Fusion and Visual Servoing Control," 2025, doi: 10.48550/ARXIV.2510.23003.

[70]. N. Vemuri, N. Thaneeru, and V. M. Tatikonda, "Smart Farming Revolution: Harnessing IoT for Enhanced Agricultural Yield and Sustainability," *Journal of Knowledge Learning and Science Technology ISSN 2959-6386 (online)* , vol. 2, no. 2, p. 143, Jul. 2023, doi: 10.60087/jklst.vol2.n2.p148.

[71]. S. H. Abdulhussain *et al.* , "A Comprehensive Review of Sensor Technologies in IoT: Technical Aspects, Challenges, and Future Directions," *Computers* , vol. 14, no. 8, p. 342, Aug. 2025, doi: 10.3390/computers14080342.

[72]. R. R. Shamshiri *et al.* , "Digitalization of agriculture for sustainable crop production: a use-case review," *Frontiers in Environmental Science* , vol. 12. Frontiers Media, Jul. 25, 2024. doi: 10.3389/fenvs.2024.1375193.

[73]. Singh, N. Kalra, N. Yadav, A. K. Sharma, and M. Saini, "SMART AGRICULTURE: A REVIEW," *Siberian Journal of Life Sciences and Agriculture* , vol. 14, no. 6. Naučno-innovacionnyj Centr, p. 423, Dec. 25, 2022. doi: 10.12731/2658-6649-2022-14-6-423-454.

[74]. Abdelmoneim, H. N. Kimaita, C. M. A. Kalaany, B. Derardja, G. Dragonetti, and R. Khadra, "IoT Sensing for Advanced Irrigation Management: A Systematic Review of Trends, Challenges, and Future Prospects," *Sensors* , vol. 25, no. 7. Multidisciplinary Digital Publishing Institute, p. 2291, Apr. 04, 2025. doi: 10.3390/s25072291.

[75]. W. B. Abdulaziz and M. S. Croock, "Review on cyber-security for optimized and smart irrigation systems," *TELKOMNIKA (Telecommunication Computing Electronics and Control)* , vol. 21, no. 1, p. 133, Oct. 2022, doi: 10.12928/telkomnika.v21i1.24234.

[76]. Mahmud, "AN IOT-ENABLED DECISION SUPPORT SYSTEM FOR CIRCULAR ECONOMY BUSINESS MODELS: A REVIEW OF ECONOMIC EFFICIENCY AND SUSTAINABILITY OUTCOMES," *American Journal of Scholarly Research and Innovation* , vol. 4, no. 1, p. 250, Jan. 2025, doi: 10.63125/28kdxg31.

[77]. Bekee, M. Segovia, and C. Valdivia, "Adoption of smart farm networks: a translational process to inform digital agricultural technologies," *Agriculture and Human Values* , vol. 41, no. 4, p. 1573, Apr. 2024, doi: 10.1007/s10460-024-10566-3.

[78]. G. Saha, F. Shahrin, F. H. Khan, M. A. Meshkat, and A. A. M. Azad, "Smart IoT-driven precision agriculture: Land mapping, crop prediction, and irrigation system," *PLoS ONE* , vol. 20, no. 3, Mar. 2025, doi: 10.1371/journal.pone.0319268.