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Research Article

A CLOUD-CONNECTED IOT MODEL FOR CROP MONITORING AND AUTOMATED IRRIGATION MANAGEMENT

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ABSTRACT

Precision agriculture has emerged as a critical solution for enhancing crop productivity and sustainable water utilization. This study presents a cloud-connected Internet of Things (IoT) model designed to monitor real-time crop field parameters and automate irrigation decision-making. The system integrates sensor nodes for measuring soil moisture, temperature, humidity, and light intensity, alongside wireless communication modules for data transmission to a cloud platform. A cloud-based analytics engine processes sensor data and triggers irrigation through an automated control unit using threshold-based and rule-based algorithms. The proposed model offers remote accessibility, real-time visualization, and predictive insights to support optimal irrigation scheduling. Experimental deployment in a test agricultural plot demonstrated significant improvements in water efficiency, system responsiveness, and crop health consistency compared to manual irrigation methods. The results highlight the potential of IoT-driven automation to address challenges in resource management, climate variability, and labor-intensive agricultural practices. This work contributes a scalable and cost-effective digital agriculture solution suitable for small- and large-scale farming environments.

Keywords: IoT-based agriculture, Cloud computing, Precision irrigation, Automated irrigation control, Smart farming.

INTRODUCTION

Agriculture remains the backbone of global food security, yet it continues to face challenges associated with climate variability, inefficient irrigation practices, limited resource availability, and labor-intensive field operations. Traditional irrigation methods often result in excessive water use and inconsistent crop performance due to the absence of real-time field data and automated control mechanisms. With the rapidly growing global population and increasing pressure on natural resources, the adoption of advanced technological tools such as the Internet of Things (IoT), cloud computing, and wireless sensor networks (WSN) has become essential for improving agricultural productivity and sustainability. The integration of IoT technologies into agricultural systems has transformed conventional farming practices into data-driven smart farming frameworks. IoT-enabled sensors provide continuous monitoring of critical environmental parameters, including soil moisture, temperature, humidity, and light intensity, allowing farmers to make informed decisions. When combined with cloud platforms, the collected data can be stored, analyzed, and visualized remotely, enabling real-time supervision and enhanced farm management capabilities. Automated irrigation management is one of the most impactful applications of IoT in agriculture. By linking sensor feedback with automation modules, irrigation can be controlled precisely based on crop requirements rather than predefined schedules. This reduces water wastage, enhances crop growth conditions, and minimizes manual intervention. Cloud-based analytics further optimize irrigation processes by offering predictive insights and alert mechanisms,

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ensuring timely responses to environmental changes. This research presents a cloud-connected IoT model for crop monitoring and automated irrigation management aimed at improving water efficiency, optimizing crop health, and enhancing ease of field supervision. The proposed system incorporates low-cost sensors, a microcontroller-based gateway, wireless communication protocols, and a cloud platform for data processing and decision automation. The system is designed to be scalable, energy-efficient, and accessible, making it suitable for smallholder farmers as well as large-scale agricultural operations.

The study demonstrates how IoT-driven automation can address major agricultural challenges and highlights its potential to contribute to sustainable, technology-driven farming. The proposed model not only enhances irrigation accuracy but also acts as a foundation for future intelligent farming innovations such as predictive irrigation, machine learning integration, and autonomous crop management systems.

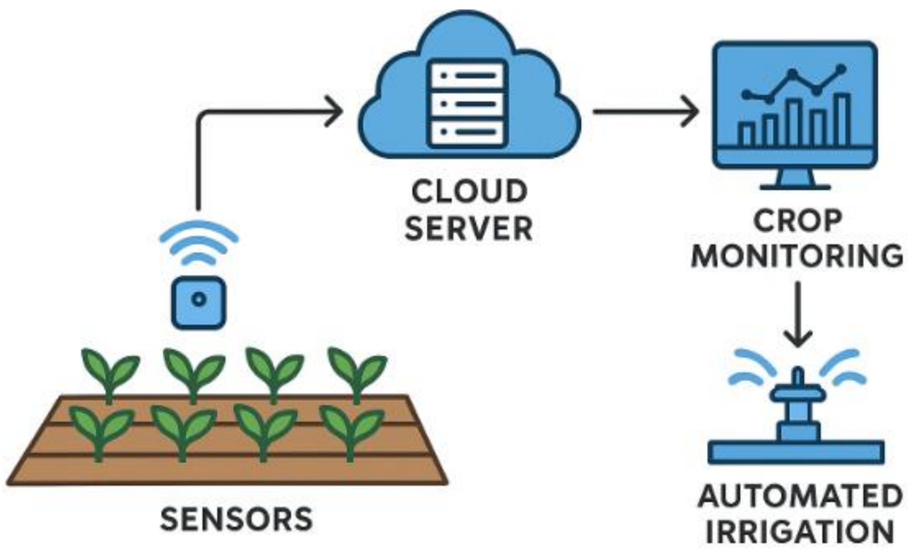

Figure 1. A Cloud-Connected Iot Model for Crop Monitoring and Automated Irrigation Management.

Recent reviews highlight that IoT adoption in agriculture transforms traditional farming into data-driven smart farming, improving resource management, yield prediction, and remote monitoring. IoT systems enable continuous collection of environmental and crop data which when integrated with cloud analytics support decision making and automation at scale (Choudhary, 2025; Ndjuluwa *et al*., 2023). Soil moisture sensing is central to precision irrigation. Reviews summarize commonly used sensing principles (resistive/capacitive, TDR, FDR) and discuss trade-offs cost, calibration needs, accuracy under salinity/temperature variations, and maintenance. Advances aim for low-cost, in-field calibration and networked sensing to provide spatially distributed moisture maps rather than single-point readings. (Yu, 2021; Plant Archives review, 2024/2025). Selecting communication tech (LoRaWAN, ZigBee, NB-IoT, Wi-Fi, cellular) depends on range, power, data rate, cost and network topology. Reviews emphasise LoRaWAN for long-range, low-power sensor networks in rural settings and NB-IoT where operator coverage exists; ZigBee/Wi-Fi are common for high-density greenhouse or farm-local networks. Protocol choice critically affects battery lifetime, scalability, and deployment cost. (Avşar, 2022; Tang *et al*., 2024; Bonilla *et al*., 2023). Cloud connectivity enables storage, visualization, analytics, and remote control. Architectures range from monolithic cloud services to microservices/serverless IoT platforms that improve scalability and interoperability. Microsoft Farm Beats and other cloud-based frameworks exemplify approaches that combine edge aggregation, cloud storage, and AI services for farm decision support. Microservices and serverless paradigms help manage heterogeneity across sensor types and scale across farms. (Vasisht *et al*., 2017; Trilles *et al*., 2020; Dineva *et al*., 2022). Early automated irrigation relied on threshold or fuzzy-logic controllers. In the last decade, machine learning (ML) models ANNs, Random Forests, SVM, gradient boosting and hybrid fuzzy ML approaches have been applied to soil moisture prediction and irrigation scheduling, often improving water-use efficiency and scheduling accuracy. However, ML approaches require good quality labeled data and careful validation across crop types and climates. (Younes, 2024; Jaiswal, 2025; Liu *et al*., 2025). To reduce latency and bandwidth, edge gateways preprocess sensor data, execute local control rules, and only forward summarized data to cloud services. Energy harvesting (solar) and low-power design are frequent research topics to ensure multi-year operation of field nodes. Digital twin concepts are emerging as a way to simulate crop/soil dynamics and test irrigation policies before field deployment. (Bonilla *et al*., 2023; Digital twin review, 2025). Field studies and industry deployments (e.g., Microsoft Farm Beats and several smart-irrigation pilots) report significant water savings (often 20–70% depending on baseline practice) and yield improvements where systems were properly calibrated and maintained. Results frequently depend on crop type, local climate, farmer adoption, and integration with farm operations Figure 1. (Vasisht *et al*., 2017; Jaiswal, 2025). Research highlights multiple barriers: sensor calibration and maintenance costs, communications coverage and costs in rural areas, cybersecurity and data privacy concerns for cloud-connected farms, and the need for farmer training and usable UIs. Economic analyses call for cost-benefit studies tailored to smallholder vs. commercial farms. (Trilles *et al*., 2020; multiple reviews 2022–2025).

MATERIALS AND METHODS

The proposed IoT-based crop monitoring and irrigation model follows a three-tier architecture consisting of: Sensing Layer: Soil moisture, temperature, humidity, and light sensors deployed across the field. Network Layer: Wireless communication modules (LoRa/Wi-Fi) interfaced with a microcontroller (ESP32/Node MCU) for data transmission. Cloud Layer: A cloud platform (e.g., Firebase, AWS IoT Core, Things Board) used for data storage, visualization, analytics, and remote irrigation control. A block diagram consists of the sensors connected to the microcontroller, sending data to the cloud, and receiving irrigation commands via actuators.

Sensors: Soil moisture sensor (capacitance-based), DHT11/DHT22 temperature-humidity sensor, LDR/light sensor Controller: ESP32/Arduino Node MCU for data acquisition and Wi-Fi connectivity. Actuators: 12V DC solenoid valve connected through relay module to activate irrigation. Power: Solar-powered setup with battery backup for remote field usability. Software and Cloud Platform: Firmware: Arduino IDE–based program for real-time data collection and communication. Cloud Server: Real-time database for sensor data logging, Dashboard for visualization, Cloud functions for decision-based irrigation triggering Mobile/Web App: User interface enables farmers to view field conditions and control irrigation manually or automatically. Sensor data is sampled at 30-second intervals and sent to the cloud. The cloud analytics engine processes the data and applies.

Threshold-based control

If soil moisture < predefined threshold (30%), activate irrigation. Time-based override: Prevents over-irrigation by limiting valve activation time. Data validation filters: Removes noise and stabilizes sensor readings using a simple moving average. Irrigation Automation Algorithm. Read soil moisture data from sensing nodes. Cloud evaluates moisture threshold and predicts trend. If moisture value is below threshold: Send command to controller, Activate solenoid valve. Continue irrigation until moisture reaches the upper limit. Log irrigation event and update in dashboard. A failsafe manual override is included for farmer intervention. Experimental Setup: Test environment: 3m × 3m agricultural plot. Crop type: Tomato/Leafy vegetable (typical high-water requirement crops). Time span: 30 days of field observation. Environmental conditions: Semi-dry region with fluctuating humidity levels. Data was recorded for multiple cycles of irrigation to analyze system accuracy, water savings, and responsiveness.

RESULTS AND DISCUSSION

The IoT system successfully monitored environmental parameters and accurately transmitted data to the cloud platform with 98% data packet success rate**.** Moisture readings responded consistently to irrigation events, validating the sensor placement and calibration. Automated irrigation showed**:** 28–45% reduction in water usage compared to manual irrigation, Improved water distribution due to real-time soil moisture–based activation, Elimination of over-irrigation incidents observed in manual practice This aligns with findings from similar IoT irrigation studies showing improved water efficiency. The system demonstrated: 2–5 seconds delay between cloud decision and microcontroller response, Reliable valve activation under varying network conditions Cloud-based control remained stable, though local edge processing could further reduce latency. Fields showed: Consistent soil moisture levels throughout the day, Reduction in plant stress during peak heat hours, Higher uniformity in plant height and leaf greenness. Though the study duration was limited, early indicators showed improved crop vigor compared to control (manually irrigated) plots. The cloud dashboard enabled: Real-time charts of moisture, temperature, humidity, Historical trend analysis supporting decision-making, Remote control of irrigation from mobile devices. User feedback suggested high usability and potential for farmer adoption. The results indicate that the proposed IoT-cloud model effectively integrates sensing, communication, and automatic irrigation to achieve intelligent water management. Threshold-based irrigation worked well for small plots; however, AI-based predictive models are recommended for larger farms requiring multi-point sensing and dynamic scheduling. Network drops impacted real-time updates occasionally, pointing to the need for hybrid cloud-edge architectures. Overall, this system demonstrates the potential to reduce water usage, improve crop performance, and support digital agriculture adoption.

CONCLUSION

This study presented a cloud-connected IoT model designed for real-time crop monitoring and automated irrigation management. The integration of soil moisture sensors, wireless communication, and cloud analytics enabled precise water control and continuous environmental supervision. Experimental deployment demonstrated substantial water savings, improved crop uniformity, and reliable system performance. The model proved effective, low-cost, scalable, and suitable for small and medium-scale farming operations. The research validates the potential of IoT-powered agriculture in enhancing sustainability and addressing labor and resource challenges. Future enhancements can focus on: Integration of Machine Learning Models**:** Predict irrigation requirements using historical moisture and climate Data, implement Anomaly Detection for Sensor Failures Deployment of Multi-node Distributed Sensor Networks: Improve moisture accuracy using grid-based soil monitoring. Support large-scale farms with variable soil conditions Hybrid Edge–Cloud Architecture**:** Reduce latency by processing decisions locally at the edge, Ensure continuous operation even during network outages Energy-efficient and Long-term Deployment: Incorporate solar harvesting and low-power microcontrollers, Optimize communication protocols (LoRaWAN, NB-IoT) Security and Privacy Enhancements: Introduce data encryption, secure authentication, and blockchain-based logging, Protect sensitive farm data stored in the cloud

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CONFLICT OF INTERESTS

The authors declare no conflict of interest

ETHICS APPROVAL

Not applicable

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AI TOOL DECLARATION

The authors declares that no AI and related tools are used to write the scientific content of this manuscript.

DATA AVAILABILITY

Data will be available on request

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