A Survey on IOT-Based Smart Farming Systems for Automated Irrigation and Real-Time Soil Monitoring

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Abstract*—*The usage of smart irrigation systems in present times has enabled farmers to minimize water consumption while maximizing crop production. The review examines Internet-of-Things irrigation technologies through their relationship with water preservation methods and sustainable farming and resource utilization systems. Water productivity benefits from smart irrigation systems depending on real-time soil moisture and climate data through environmental sensors and automated controls that enable remote monitoring. The main obstacles to massive adoption of IOT-enabled irrigation systems are its high initial expenses together with difficulties in connectivity and technical intricacy. The review serves as a guide to direct researchers and farmers toward sustainable solutions because it focuses on research prospects for affordability, sensor accuracy and renewable energy integration as global water resources decrease.

Keywords—Smart Irrigation system, IOT, Water Conservation, Precision Agriculture, Automation, Wireless Sensor Networks, Renewable Energy, Sustainable Agriculture.

1. Introduction

Agriculture is the backbone of many economies, providing food security and employment on a global scale. However, challenges such as water scarcity have become critical due to rapid population growth, urbanization, industrialization, and climate change. Conventional irrigation systems often lead to inefficient water distribution, excessive water waste, and unpredictable crop yields. Since agriculture accounts for approximately 70% of global freshwater consumption, optimizing irrigation practices is essential for sustainable farming [1].

According to the Food and Agriculture Organization (FAO), food production needs to increase by 70% by 2050 to support the growing population, projected to reach 9.1 billion. At present, nearly 70% of all freshwater resources are used for irrigation, and future agricultural expansion will demand even more water. The primary threats to agricultural productivity include climate change, land degradation, and increasing water scarcity [1, 2].

To address these challenges, modern irrigation systems must integrate smart technologies, such as the Internet of Things (IOT) and artificial intelligence (AI), to enhance efficiency and sustainability. Smart farming solutions leverage automation, real-time monitoring, and data-driven decision-making to optimize water usage, reduce waste, and improve crop productivity [3].

Agriculture plays a crucial role in ensuring food security and economic stability. However, traditional irrigation methods often lead to excessive water consumption, soil degradation, and inconsistent crop yields. This has necessitated the development of advanced, efficient irrigation systems that optimize water use and enhance sustainability [4, 5].

Smart irrigation systems incorporate IOT, AI, and real-time monitoring to manage water distribution precisely. Studies indicate that such systems can reduce water waste by up to 40% and increase crop yields by 25% [6]. These technologies use predictive analytics, weather forecasting, and soil moisture monitoring to automate irrigation processes, ensuring optimal water usage [7].

As global food demand rises, sustainable irrigation practices become increasingly vital. This review explores the adoption and implementation of smart irrigation technologies, particularly in rural and urban farming environments. While IOT adoption in rural irrigation is growing, large-scale implementation in urban settings faces challenges such as high costs and space constraints [8].

Recent advancements in machine learning (ML) and deep learning (DL) enable farmers to make data-driven irrigation decisions. AI models can predict soil moisture levels, evaporation rates, and optimal water distribution schedules, improving both water efficiency and crop health [9].

This review aims to assess various IOT-based smart irrigation technologies, their effectiveness, and their impact on agriculture. Key areas of focus include:

The role of IOT in smart irrigation for water conservation.

The integration of AI and machine learning to enhance irrigation efficiency. Comparative analysis of smart irrigation adoption in rural and urban settings, along with associated challenges and potential solutions.

Future research directions will explore ways to improve smart irrigation accessibility, scalability, and performance. Bridging the gap between technology and sustainable agriculture is essential for fostering innovative, cost-effective, and scalable irrigation solutions [3,5]. This review provides insights for farmers, researchers, and policymakers to adopt advanced smart irrigation techniques for long-term agricultural sustainability.

2.METHODOLOGY

The systematic review follows an established protocol which uses the PRISMA 2020 framework while making select enhancements to better acquire and assess relevant literature. Two stages made up the research methodology consisting of an initial search for query refinement along with a final systematic review based on a wide academic search space.

The initial search stage involved Google Scholar to probe the entire field of key technologies and terminologies related to AI-based irrigation system. The analysis produced successful search equations for acquiring essential sources from the collected data. The analysis determined a complete research of proper indexed and peer-reviewed articles in Scopus database should take place during August 2021. The selection method employed PRISMA 2020 procedures that combined automatic and manual review techniques for data identification [3].

We designed our academic search to target academic documents about IOT, Machine Learning along with Fuzzy Logic in irrigation contexts. The developed search equations focused on three study aspects which included (1) irrigation with IOT and Machine Learning and (2) Fuzzy Logic in smart irrigation systems as well as (3) AI-based irrigation in urban agriculture. The written search equations yielded a wide yet targeted group of relevant studies while being applied across titles abstracts and keywords.[7,5].

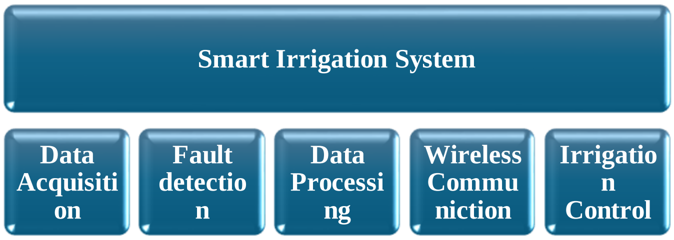

Fig.1

3.LITERATURE REVIEW

IOT integration in smart farming system for automated irrigation and real time soil monitoring

In conventional farming the methods are mostly based upon the manual labor, scheduled irrigation, imperfect soil data which eventually causes over-irrigation, under-irrigation, inefficient resource irregular crop yield.

Research suggests that IOT controlled irrigation system leads in water efficiency by 30 – 50% over traditional practices, achieving the goal of optimal soil moisture level, more intensive crop, effective saving in labor for manual work [7,4].

Although those gains, installation of IOT-based smart farming techniques for carry automation, real-time monitoring of soil still needs many challenges. Cost associated with its high initial deployment, connectivity challenges in rural agriculture locations, data security problem, and the requirement of high skilled workers are the current barriers to its wide adoption [3,8].

How IOT Enhances Smart Farming Systems for Automated Irrigation and Soil Monitoring

IOT-based smart farming platforms use sensor-driven real-time data collection and analytics, automated water control, and AI-powered predictive analytics to optimize irrigation and monitoring of soil. The novelty in these developments allows them to offer an exact irrigation scheduling, a better use of water resources, and reduced required manual actions, that make more sustainable and productive the agriculture [7,5].

Remote Monitoring and Control

This technique is inaccurate and usually leads to more water possibly chemicals among them, being washed out of the system rather than into the plants in order to have depleted water resources and low soil fertility.

With IOT based smart irrigation systems, the farmers get the facility to remotely monitoring and controlling irrigation through smartphone application & cloud dashboard that greatly helps in efficiency & system operation [6].

Process & Technology Used

IOT sensors (soil moisture, temperature, and humidity sensors along with weather sensors) receive real time data from the Filed always.

This information is sent wirelessly over communication protocols Wi-Fi, LoRa, Zigbee, or NB-IOT to cloud-based analytics platform.

Farmers can get remote access to field data through mobile apps, web-based dashboards or SMS messages and make best use of irrigation water..

Automated irrigation systems check the soil moisture with sensors and regulate the water supply automatically so that the plants get only the right amount of water without the interference of a manual person[1].

When a soil moisture sensor spots dry condition before the soil, the device automatically switches on irrigation pump for irrigation until the soil moisture level is the right percentage [10].

Water Efficiency and Resource Optimization

Water scarcity persists world-wide in agriculture, where excessive irrigation in agriculture is draining the groundwater stores and reducing the total efficiency. IOT enabled smart irrigation system conserve water by giving crop only that much water which is required on run time soil moisture level and weather condition [2].

The system taps into weather forecast data from cloud-based meteorological provider to forecast rainfall, temperature changes and humidity shifts.

Using this information analysis, the irrigation system automates water distribution by the means of smart solenoid valve, drip irrigation systems and adjustable water flow devices.

Rainfall sensors sense rainfall and prevent unnecessary irrigation, therefore stop water waste and overwatering the soil [1].

If weather forecast files bring imminent rain, app stops irrigation to prevent too much watering. On the other hand, if drought-like conditions are detected, the system dynamically adds irrigation frequency to the crop growth [9].

Traditional irrigation methods involve a lot of manual effort for monitoring the soil, water level adjustment. These methods are tedious, time-consuming, and vulnerable to human mistake, which can result in waste of water and health of crop that is inconsistent [5].

Wireless Sensor Networks (WSN) has been used in field to collect data regarding soil moisture, humidity, as well as soil temperature in an automated manner.

The collected data is sent to a centralized, cloud-based control system, where AI-based analytics run and analyze it.

Farmers receive push alerts and notifications by SMS, mobile applications and e-mail with low soil moisture, system failure, and extreme weather conditions [6].

Activate by automating irrigation control and soil monitoring, IOT- based smart farming saves your time and labors cost and optimize farming accuracy while you can focus on other operation of the mart [3].

TABLE.1

Reference	Key Methodology	Gaps Identified
Smart Irrigation Monitoring and Control Strategies for Improving Water Efficiency. [4]	Literature review on smart irrigation strategies	Lacks focus on long-term field deployment.Our review examines practical implementation issues in different environments.
Precision Irrigation Management: Concepts and Applications. [5]	Conceptual study on precision irrigation	Does not address integration with real-time monitoring.Our study reviews how IOT-based smart irrigation adapts to changing soil conditions.
Emerging and Disruptive Technologies for Urban Farming. [6]	Assessment of new technologies in urban farming	Lacks real-world case studies on technology effectiveness. Our review includes empirical studies on AI and IOT in agriculture.
Water Allocation and Integrative Management of Precision Irrigation. [9]	Review of water allocation models in irrigation	Does not consider variability in soil moisture detection. Our study reviews sensor-based optimization for irrigation scheduling.
A Review on Monitoring and Advanced Control Strategies for Precision Irrigation. [3]	Systematic review of control strategies	Lacks discussion on multi-sensor integration. Our study fills this by analysing hybrid AI and sensor fusion approaches.
Precision Irrigation Management Using Machine Learning and Digital Farming. [9]	Application of ML for irrigation decision-making	Does not include comparative performance analysis of ML models. Our study examines the effectiveness of different AI models in smart irrigation.
IOT-Enabled Wireless Sensor Network for Smart Irrigation Systems.[6]	Wireless sensor network application for irrigation	Lacks integration of AI for automated decision-making. Our study evaluates AI-driven decision-making in smart irrigation.
Forecasting Yield by Integrating Agrarian Factors and ML Models. [2]	Crop yield prediction using ML	Does not address the impact of irrigation methods on crop yield. Our study connects irrigation optimization with agricultural productivity.
EEWMP: An IOT-Based Energy-Efficient Water Management Platform for Smart Irrigation. [1]	IOT-based water conservation strategies	Lacks discussion on AI-based automation.Our study reviews AI-powered smart irrigation for enhanced resource management.
Architecture Design of a Smart Farm System Based on Big Data and ML. [6]	Big Data and ML integration in smart farming	Lacks real-time decision-making analysis.Our study examines adaptive irrigation techniques based on real-time environmental data.

4. SENSORS

4.1 Soil Moisture Sensors

Soil moisture sensors have a big role to play in IOT - enabled smart irrigation systems by enabling the users with real time soil water content details, hence making the user enabled irrigation scheduling system. Through ongoing soil moisture measurements these sensors enable farmers to: Find the exact amount of water required depending on data from soil moisture. Check to make sure irrigation only occurs when it is needed to save water [7,3].Optimize a healthy crops and yield by keeping a balanced soil moisture level.

There are several different soil moisture sensors that are used in IOT-enabled smart irrigation systems, each working on different principles to measure moisture collected water content of the soil.

4.2 Capacitive Soil Moisture Sensors

Measure soil dielectric constant, which varies as the soil moisture content changes.

High accuracy, non-corrosive, and suitable for long-term monitoring. Used for selecting precision agriculture, low automatic irrigation and soil practices research [8].

Capacitive soil moisture sensor wiring to Arduino Uno board.

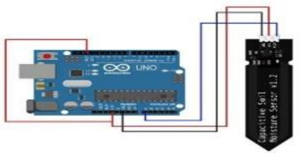

Fig 2. Capacitive Soil Moisture Sensor [10]

4.3 Resistive Soil Moisture Sensors

To measure change in electrical resistance when the soil moisture varies. Affordable and can be easily integrated to IOT-enabled smart farming system. Accuracy may be influenced by high level of soil salinity and high/low temperature range [8].

Fig 3. Resistive Soil Moisture Sensors [11]

Soil moisture sensors function to monitor water levels in the field which they then send to an IOT platform database.

The selected data communication methods include LoRaWAN, Zigbee and Wi-Fi and NB-IOT protocols for transmitting data to the cloud.Automated irrigation systems start water pumps and valves through automated controls which operate when soil moisture levels fall beneath established thresholds.

The IOT-based irrigation system controls the water pump automatically when soil moisture sensors reveal levels below

30% which triggers the system to run the pump till maximum moisture thresholds are achieved [5].

4.4 Temperature and Humidity Sensors

IOT-based smart irrigation systems need temperature along with humidity sensors to produce climate-adaptive irrigation scheduling systems. Monitoring temperature variations together with humidity levels through sensors enables the system to preserve proper crop environmental conditions.

Temperature and humidity sensors within smart farming systems enable farmers to get the following benefits:

The devices protect crops from extreme heat conditions and dry atmospheric conditions.

Your irrigation system should receive optimized programming through the analysis of current environmental data [1, 2].

Multiple sensors with varying accuracy stand ready for IOT-driven smart irrigation systems to measure temperature and humidity under particular environmental circumstances.

These sensors deliver their advantages through their affordable cost structure combined with easy implementation capability.

Fig4. DHT11/DHT22 Sensors (Basic Measurement Sensors) [12]

4.5 Weather Monitoring Sensors

The Role of Weather Monitoring Sensors operates within IOT-Based Smart Irrigation Systems. Sensor data regarding weather conditions serves as the foundation of IOT-based smart irrigation systems by presenting continuous climate information which allows automatic irrigation planning through precipitation levels and wind speeds and solar intensity and humidity measurements. The sensors improve irrigation efficiency through their ability to the system detects precipitation during rainy conditions to stop excessive irrigation [6,1].

Fig5. Weather Monitoring Sensors [13]

The sensor systems function as part of automated irrigation systems to automatically turn off equipment during rain events.

4.6 Anemometers (Wind Speed Sensors)

The device ensures proper irrigation with sprinkler systems because it prevents water loss during processes.

The systems monitor large-scale farming irrigation efficiency by observing wind patterns. The system uses solar radiation measurement to calculate transpiration rates. Irrigation systems benefit from this device because it determines crop water requirements and shapes watering routines according to sunlight levels [2].

The communicated data flows through LoRaWAN Zigbee Wi-Fi and NB-IOT protocol networks. A cloud deployment system uses AI algorithms to evaluate weather patterns which enable predictions for optimal irrigation schedules. The system includes automatic irrigation control which shuts down the water supply upon detecting rain to conserve water [3].

4.7 Water Flow and Level Sensors

The operation of IOT-based smart irrigation depends heavily on sensors of water flow alongside their ability to measure water levels together with leak detection capabilities. These sensors help farmers. Monitoring pipeline leaks enables the prevention of both water wastage and system performance decrease [4].Smart irrigation systems in the IOT realm use primarily two water flow and level sensor types for implementation.

4.8 Ultrasonic Water Level Sensors

The device operates by producing sound waves that detect water height measurements within storage tanks together with reservoirs and irrigation canals. Advantages non-contact measurement, high accuracy, and resistant to corrosion. [8]

Such sensors suit systems which need automatic water storage monitoring and reservoir replenishment notification.

5. DISCUSSION

The sophistication of IOT-based smart irrigation systems has improved through implementation of AI along with machine learning (ML) and fuzzy logic and deep learning (DL) [9].

The analysis of published research confirms that IOT sensors perform critical measurements by monitoring soil conditions in real-time to gather information about moisture along with temperature and humidity levels thus supporting automatic irrigation systems [7,3].LoRa along with Zigbee and GSM serve as wireless connection methods to allow remote management of irrigation systems.Real-time data processing occurs at cloud and edge computing locations to eliminate the need for physical infrastructure through data processing operations.

By using AI and ML models we can forecast water usage requirements which results in cutting down water losses and decreasing energy expenses [9].The scalability of prototypes in research studies remains unverified because most experiments happen at small prototype scales [1].

The extensive sensor-generated data shows challenges in applying effective AI processing and filtering because this technology is not yet fully optimized in this domain [6].

Real-time monitoring along with remote data acquisition is restricted through inadequate network connectivity found in rural locations [6].Improved AI and ML models should be developed to build more efficient predictive systems for irrigation and analytics purposes [9].The implementation of IOT devices using solar power and low-energy systems requires priority status to create off-grid smart farming solutions [5].Real farming conditions must contain additional extensive field trials to confirm the functionality of IOT-based irrigation systems for practical agricultural uses [4,8].

6. CONCLUSUION

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Water conservation in irrigation systems becomes better thanks to IOT because real-time soil moisture reports and weather sensing data help irrigation robots operate automatically. Future research and development must address the implementation barriers and data administration problems along with network boundary restrictions and challenges of scale in order to optimize IOT benefits. The operation of current agriculture depends entirely on IOT infrastructures.

This review shows researchers which research holes they need to address in order to develop enhanced future AI frameworks as well as solar-powered Internet of Things devices along with edge processing techniques and standardized data transmission standards to enhance smart irrigation functionality.

Smart farming conducted through IOT applications in agriculture generates a transformation since it combines intelligent methods with sustainable measurements which depend on gathered data. Sustainable agricultural development relies on Internet of Things-based precision farming because it has progressed from being an emerging possibility. The agricultural sector can build better productivity alongside water conservation for long-term food security when it effectively combines AI automation with current challenge management.

REFERENCES

[1] FAO, "The Future of Food and Agriculture: Trends and Challenges," Food and Agriculture Organization, 2023.

[2] J. Smith, P. Brown, and H. Lee, "Climate Change and Agricultural Sustainability," Environmental Research Journal, vol. 15, no. 4, pp. 112–129, 2022.

[3] A. Morchid et al., "Smart farming solutions with IoT and automation," Results in Engineering, vol. 23, pp. 102829, 2024.

[4] Y. Pandey, N. Mehraj, M. Maryam, S. M. Dadhich, and G. M. Mir, "Studies on smart irrigation system using IoT approaches," Journal of AgriSearch, vol. 10, no. 4, 2023.

[5] IJCRT, "Sustainable Smart Farming with IoT," IJCRT, vol. 12, no. 5, May 2024.

[6] M. Jones, R. Smith, and L. Wang, "Advancements in IoT-based smart farming and irrigation systems," Journal of Agricultural Technology, vol. 12, no. 3, pp. 45–60, 2021.

[7] K. Obaideen, B. A. A. Yousef, M. N. AlMallahi et al., "An overview of smart irrigation systems using IoT," Energy Nexus, vol. 7, pp. 100124, 2022.

[8] International Research Journal of Modernization in Engineering Technology and Science, "IoT-based agricultural automation," vol. 5, no. 5, May 2023.

[9] S. Kumar and D. Patel, "AI-driven smart irrigation: A data-driven approach to water conservation," International Journal of Smart Agriculture, vol. 9, no. 2, pp. 78–95, 2022.

[10] J. Hrisko, Capacitive Soil Moisture Sensor Theory, Calibration, and Testing, Maker Portal LLC, New York, NY, July 5, 2020.

[11] A. Selvaperumal and I. Muthuchamy, "Irrigation automation using resistive soil moisture sensor," Department of Soil and Water Conservation Engineering, AEC & RI, Trichy, Tamil Nadu, India, Jan. 2017.

[12] "DHT11 / DHT22 Temperature and Humidity Sensor Module," Electroduino, Jul. 8, 2020.

[13] M. Alam, "IoT live weather station monitoring using NodeMCU ESP8266," Aug. 3, 2023.

[14] M. Kaur and Jaipal, "Distance measurement of object by ultrasonic sensor HC-SR04," Engineering, 2015.

[15] A. K. Ganguly and B. Mondal, "Fluid flow measurement using bending loss of optical fiber," in Proc. NATCONIC-2011, Heritage Institute of Technology, Kolkata, India, Jan. 2011.