International Journal of Advanced Engineering, Management and Science (IJAEMS)
Peer-Reviewed Journal
ISSN: 2454-1311 | Vol-11, Issue-2; Mar-Apr, 2025
Journal Home Page: https://ijaems.com/
DOI: https://dx.doi.org/10.22161/ijaems.112.20

IOT- Based Smart Irrigation System

Deepak Saini[1], Aman Maru[2], Devesh Nagar[3], Navin Suthar[4], Kalpit Mathur[5], Kartikey Nehra[6]

[1]Electrical Engineering Dept., Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
deepaksaini@skit.ac.in
[2]Electrical Engineering Dept., Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
amanmaru107@gmail.com
[3]Electrical Engineering Dept., Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
deveshnagar2003@gmail.com
[4]Electrical Engineering Dept., Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
sutharnavin769@gmail.com
[5]Electrical Engineering Dept., Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
kalpit412@gmail.com
[6]Electrical Engineering Dept., Swami Keshvanand Institute of Technology, Management & Gramothan, Jaipur, India
kartikeynehra2021@gmail.com

Received: 22 Mar 2025; Received in revised form: 16 Apr 2025; Accepted: 22 Apr 2025; Available online: 30 Apr 2025

Abstract**—***Agriculture is a crucial sector that faces challenges, such as water scarcity, inefficient irrigation techniques, and increasing global food demand. The integration of the Internet of Things (IoT) into smart irrigation systems enhances water management, conserves resources, and improves crop yield. This study presents an IoT-based smart irrigation system that utilizes real-time environmental data to optimize irrigation schedules. This system employs soil moisture sensors, weather forecasting, and cloud computing to facilitate precise irrigation. This study demonstrates that the proposed system enhances efficiency while reducing water consumption. These results highlight the significance of automation in modern agriculture and its impact on sustainability and food security.*

Keywords**— *IoT-Based Smart Irrigation, Water Management, Sustainable agriculture, Water conservation, Remote monitoring.***

I. INTRODUCTION

Agriculture plays a vital role in the global economy and food security. However, the sector faces mounting challenges, including water scarcity, inefficient irrigation techniques, and the increasing demand for food production driven by a growing global population. Traditional irrigation methods, often relying on manual intervention and fixed schedules, contribute to water wastage and fail to address the dynamic needs of crops. With freshwater resources becoming increasingly scarce, there is a pressing need for innovative solutions that optimize water use in agriculture.

The Internet of Things offers a transformative approach to address these challenges. By integrating sensors, actuators, and communication networks, IoT-based smart irrigation systems enable real-time monitoring and control of irrigation processes. These systems collect environmental data, such as soil moisture levels and weather conditions, and use this information to adjust irrigation schedules dynamically, ensuring that crops receive the precise amount of water they need, when they need it. This targeted approach not only conserves water but also improves crop yields by preventing both underwatering and over-watering, which can negatively impact plant growth**.**

This study presents an IoT-based smart irrigation system designed to address the challenges of water scarcity and inefficient irrigation. The proposed system utilizes a network of soil moisture sensors to monitor real-time soil conditions. This data is processed using cloud computing resources to generate optimized irrigation schedules. The system automatically adjusts irrigation based on these real-time insights, ensuring efficient water use and promoting optimal crop growth. The primary goal of this research is to demonstrate the effectiveness of the proposed system in enhancing irrigation efficiency, reducing water consumption, and ultimately contributing to sustainable agriculture and improved food security. The subsequent sections of this paper will detail the system architecture, methodology, results, and implications of this research.

Previous research on IoT-based smart irrigation systems has focused on optimizing water management and enhancing agricultural productivity. Studies such as those by Kumar et al. (2022) and Rawal (2017) **[1]** have demonstrated the effectiveness of IoT in automating irrigation processes. These systems leverage real-time data from sensors like soil moisture, temperature, and humidity to reduce water and energy consumption significantly. Additionally, recent studies have integrated weather stations alongside soil moisture sensors to gather real-time meteorological data, enabling more precise irrigation scheduling and enhancing crop productivity, as noted by Singh et al. (2022) **[5].** The use of embedded systems for real-time irrigation control has also been explored, allowing for dynamic adjustments based on environmental conditions to improve water use efficiency**[7].** Furthermore, efforts to integrate solar-powered IoT devices into irrigation systems aim to reduce energy consumption while maintaining effective water management. Despite these advancements, challenges such as cost, scalability, and environmental adaptability remain, with future research directed towards refining algorithms for drought stress management and improving water productivity in agriculture. Overall, these studies highlight the potential of IoT-based smart irrigation systems in addressing modern agricultural challenges and provide a strong foundation for further research in precision agriculture technologies.

II. METHODOLOGY

The development of the IoT-based smart irrigation system involved the integration of hardware and software components to automate irrigation processes and optimize water usage. The system was designed to monitor environmental parameters, analyze data in real-time, and control irrigation schedules based on predefined thresholds.

A. *System Design and Components*

1. Sensors:

The proposed system utilized a combination of sensors and microcontrollers to collect and process data. Sensors are the backbone of the system, providing real-time data on environmental and soil conditions. The following sensors are commonly used:

- **Soil Moisture Sensor**: This sensor measures the volumetric water content in the soil, which is crucial for determining when irrigation is needed**[5].** It provides analog or digital output that the microcontroller processes to assess soil dryness or wetness. Advanced models also monitor salinity and electrical conductivity, offering insights into soil health.
- **Temperature and Humidity Sensor (DHT11)**: This sensor tracks environmental temperature and humidity levels. These parameters are vital for calculating evapotranspiration rates, which influence irrigation schedules.
- **Weather Sensors**: Some systems include weather sensors to monitor rainfall, humidity , temperature. These sensors help adjust irrigation schedules dynamically based on local weather conditions.

The sensors are strategically placed across the field to ensure comprehensive data collection.

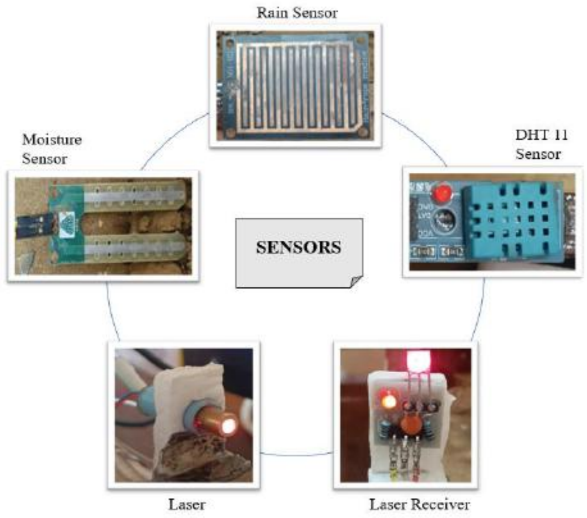


Fig.1 Types of sensors used

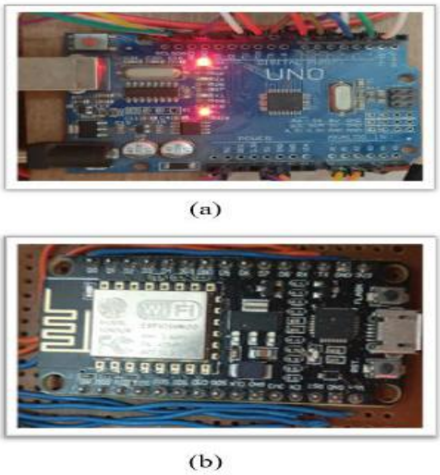
2. Microcontroller:

The microcontroller acts as the central processing unit of the system:

- *Arduino UNO* processes data from connected sensors and executes commands such as turning on/off water pumps or valves. *Node MCU ESP8266* microcontroller is widely used due to its built-in Wi-Fi module, which facilitates seamless communication with cloud platforms.

Arduino UNO is a microcontroller board based on the *ATmega328P*. It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Node MCU's ability to handle both data processing and wireless communication makes it ideal for IoT applications.

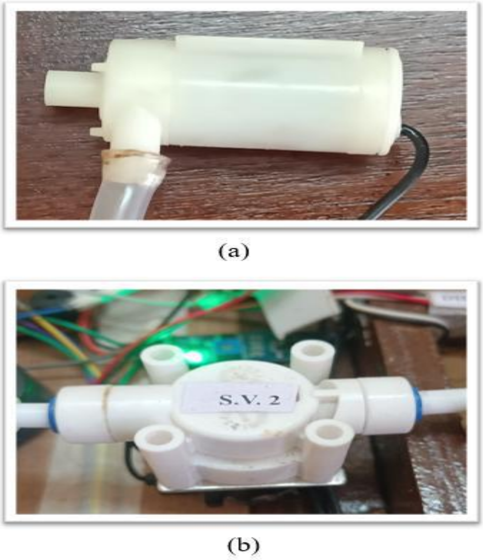

(a)

(b)

Fig. 2 (a) Arduino UNO and (b) ESP8266

3. Actuators:

Actuators are responsible for executing the irrigation process based on sensor data. A *DC motor pump* is used to supply water to the field. The pump is activated when soil moisture levels drop below a predefined threshold. *Solenoid valves* regulate water flow with high precision. They open or close based on commands from the microcontroller. These actuators ensure that water is delivered efficiently to crops without manual intervention.



(a)

(b)

Fig. 3 (a) Water Pump and (b) Solenoid Valve

4. Relay Module:

The relay module acts as an intermediary between the low-power microcontroller and high-power devices like water pumps. It allows the microcontroller to control devices operating at higher voltages (e.g., 5V–12V). A transistor circuit within the relay ensures safe operation when switching high-power devices on or off. The relay module's role is critical in enabling automation while protecting sensitive components from power surges.

Fig. 4 Relay Module

5. Power Supply:

A reliable DC power supply is essential for uninterrupted operation. The Node MCU, Arduino UNO and sensors typically operate at 3.3V or 5V DC, provided by a regulated power source. This combination of power sources ensures efficiency and reliability in remote agricultural settings.

6. Communication Module:

The communication module facilitates data exchange between system components and cloud platforms. The built-in Wi-Fi module of Node MCU ESP8266 enables real-time data transmission to IoT platform ThingSpeak.

Data collected by sensors is uploaded to the cloud for storage, analysis, and visualization. Farmers can access this data remotely, allowing them to monitor field conditions and control irrigation operations in real time. This seamless communication ensures that users stay informed about their fields' status at all times.

7. System Integration:

All components are integrated into a cohesive system through careful circuit design. The soil moisture sensor connects to the analog input pins (e.g. A0,A1,A2 and so on) of Arduino UNO. Other sensors (e.g., DHT11) connect to digital GPIO pins (e.g., D1). The relay module connects to another GPIO pin (e.g., D0) for controlling actuators like pumps or valves.

Custom algorithms programmed into the Arduino UNO process sensor data and make decisions based on predefined thresholds**[4][5].** For instance: If soil moisture falls below a set threshold, the pump is activated until optimal moisture levels are restored. Weather data can be factored in to delay irrigation if rainfall is expected.

This modular design allows scalability, enabling additional features like advanced weather forecasting or solar integration to be added as needed.

B. *Circuit Diagram*

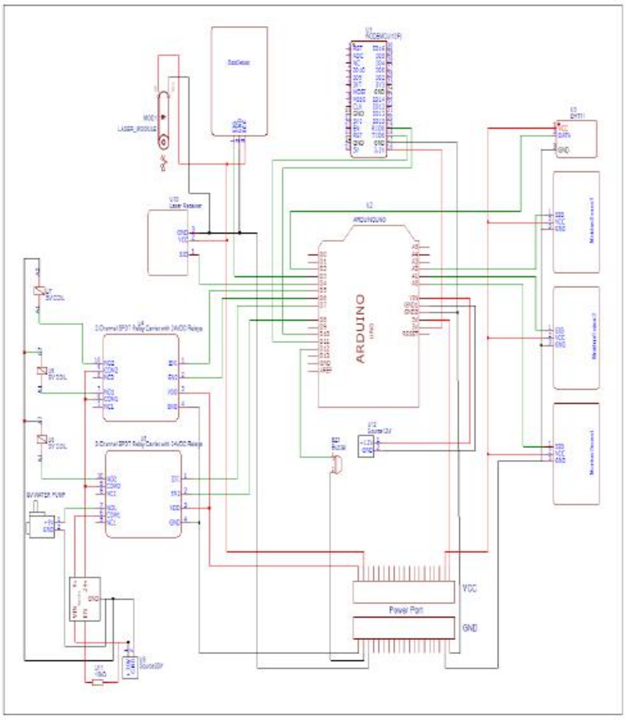


Fig. 5 Circuit Diagram

The circuit schematic for the Smart Irrigation System was designed and developed using *Easy EDA software*. This schematic represents the complete hardware architecture of the system, integrating multiple electronic components for automated irrigation based on environmental conditions.

The circuit diagram presents a detailed IoT-enabled environmental monitoring and smart irrigation system, orchestrated by an Arduino Uno microcontroller at its core. The Arduino collects data from a network of sensors, including three soil moisture sensors strategically placed at different locations (labeled Moisture Sensor 1, 2, and 3), each directly connected to individual analog input pins on the Arduino for precise moisture level readings. For security, a laser diode and receiver are implemented for intruder detection, with the receiver connected to a digital input pin to signal any interruptions in the laser beam. Although not explicitly labeled, connections suggest integration of additional sensors for temperature and humidity, critical for a comprehensive environmental overview. Actuation is managed through three 2-channel SPDT relay carriers configured to control solenoid valves, enabling targeted irrigation to specific areas based on the corresponding moisture sensor readings. These relays are linked to digital output pins on the Arduino, allowing precise control over water flow. A separate relay is dedicated to controlling a water pump, ensuring a broader irrigation response when overall moisture levels are low. An auditory alarm, in the form of a buzzer, is connected to a digital output pin to provide immediate alerts upon intruder detection. Power is delivered via a power port, distributing the necessary voltage to the Arduino, sensors, and actuators, with appropriate voltage regulation implemented where needed to ensure component compatibility and stability. The intricate arrangement allows the system to continuously monitor environmental conditions, and autonomously respond with targeted irrigation and security measures, making it highly suitable for smart agriculture and automated greenhouse applications.

C. *Flow Chart*

The flowchart illustrates a detailed process for an automated environmental control system, likely used in applications like smart agriculture or greenhouse management. The system initializes by setting up the necessary sensors (temperature, humidity, moisture, rain, and potentially a laser sensor), along with an LCD for local display and configuring the required pins for controlling external hardware. It then proceeds to read data from all the initialized sensors, gathering comprehensive environmental information. This data is then displayed on the LCD screen, providing immediate feedback to anyone present. Following this, the system checks for specific conditions to trigger automated actions. First, it assesses if it is raining; if it is, the system bypasses the intruder detection step, presumably because rain might interfere with accurate detection. If no rain is detected, the system checks for potential intruders, likely using the laser sensor; if an intruder is detected, a buzzer is activated to provide an alert, otherwise, the buzzer remains off. Subsequently, the system delves into moisture management. It evaluates moisture levels at three distinct locations (Moisture1, Moisture2, Moisture3), and if the moisture level at any of these locations is below a threshold of 500, the corresponding solenoid valve is opened, enabling targeted irrigation to that specific area; otherwise, the valve remains closed. A more general moisture check is then performed; if the overall moisture level is below 600, a pump is activated to provide broader irrigation, otherwise, the pump is turned off. Finally, all the collected sensor data is transmitted to an ESP8266 module, enabling data logging, remote monitoring, or integration with other smart systems. The system then enters a delay period before repeating the entire process, effectively creating a continuous loop of environmental monitoring and automated control. This continuous feedback loop allows for real-time adjustments and ensures optimal conditions are maintained automatically.

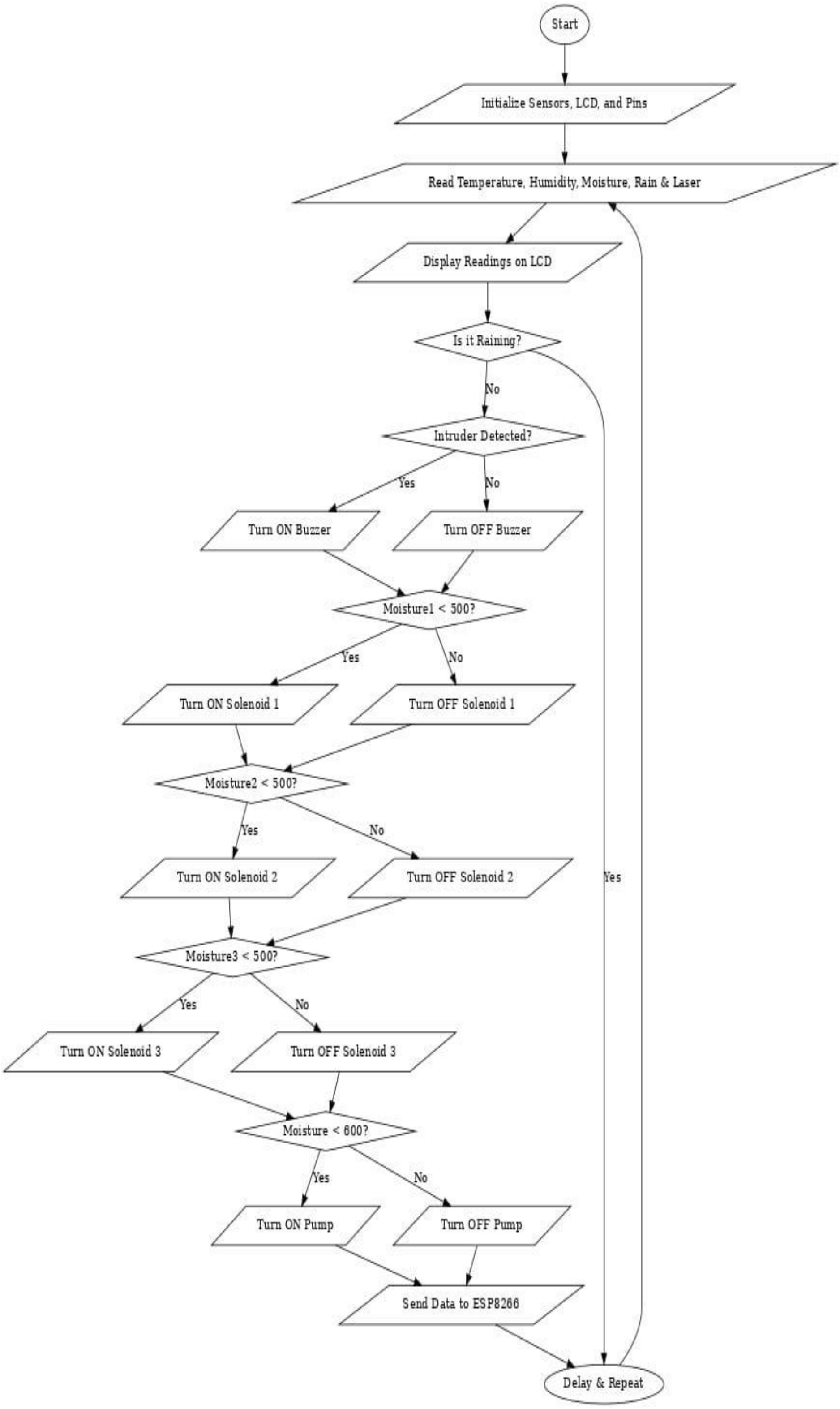


Fig. 5 Flow Chart of the process

III. ANALYSIS

The analysis of the IoT-based smart irrigation system focuses on evaluating its performance, reliability, and efficiency in managing water resources and optimizing agricultural productivity. This section outlines the key findings derived from data processing, system testing, and performance evaluation.

1. Data Analysis and Decision-Making

The system collects real-time data from sensors, including soil moisture, temperature, humidity, and weather conditions. The collected data is analyzed using predefined threshold values and intelligent algorithms to make irrigation decisions:

- **Threshold-Based Analysis**: Soil moisture levels are continuously monitored and compared against predefined thresholds**[3].** When moisture levels drop below the lower limit, irrigation is initiated; when they reach field capacity, irrigation is stopped**[5].**
- **Weather Data Integration**: Real-time weather data (e.g., rainfall predictions) is incorporated into the decision-making process to avoid unnecessary irrigation during rainy periods**[2].**
- **Edge Computing**: In some systems, data analysis is performed at the edge (e.g., on the microcontroller), reducing latency and ensuring faster decision-making.

This analytical approach ensures precise water distribution, minimizing wastage while maintaining optimal soil conditions for crop growth.

2. Performance Metrics

The system's performance was evaluated using various metrics:

- **Accuracy**: Machine learning models applied to analyze sensor data achieved high accuracy levels (e.g., 89%–98%), ensuring reliable irrigation decisions.
- **Water Savings**: Studies reported significant reductions in water usage—up to 35% compared to traditional methods—by stopping irrigation when soil moisture reached field capacity.
- **Energy Efficiency**: Solar-powered systems demonstrated sustainable operation by reducing dependency on external electricity sources.

These metrics highlight the system's ability to conserve resources while maintaining agricultural productivity.

3. Visualization and Monitoring

The analyzed data is visualized on IoT platform ThingSpeak. Users can monitor real-time sensor readings (e.g., soil moisture, temperature) through mobile or web applications. Historical data trends are displayed for better understanding and optimization of irrigation schedules.

Notifications or alerts are sent to users for critical events, such as low soil moisture or pump malfunctions. This visualization enhances user interaction with the system, enabling informed decision-making and remote control of irrigation processes.

4. System Reliability

The reliability of the system was assessed through field tests under varying environmental conditions. The system consistently maintained soil moisture within optimal ranges for crops like corn and brinjal. Fail-safe mechanisms (e.g., stopping pumps during sensor malfunctions) ensured uninterrupted operation. These results demonstrate that IoT-based smart irrigation systems are robust and adaptable to diverse agricultural settings.

5. Challenges Identified

Despite its advantages, certain challenges were observed during analysis:

- **Scalability**: Expanding the system for larger fields requires additional sensors and communication modules, increasing costs.
- **Environmental Adaptability**: Extreme weather conditions (e.g., heavy rainfall) may affect sensor accuracy or communication reliability.
- **Data Security**: Protecting sensitive agricultural data from cyber threats remains a concern in IoT systems.

IV. RESULTS

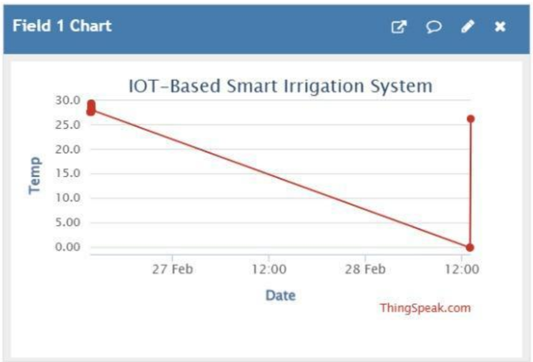


Fig. 6 Field 1: Temperature

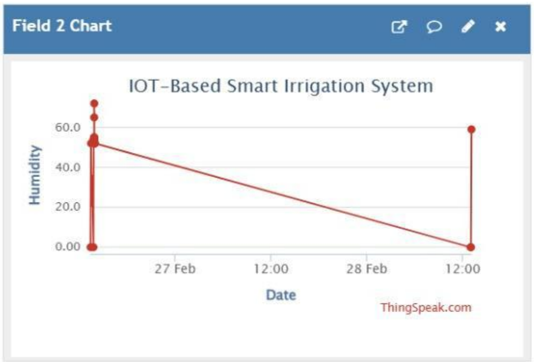


Fig. 7 Field 2: Humidity

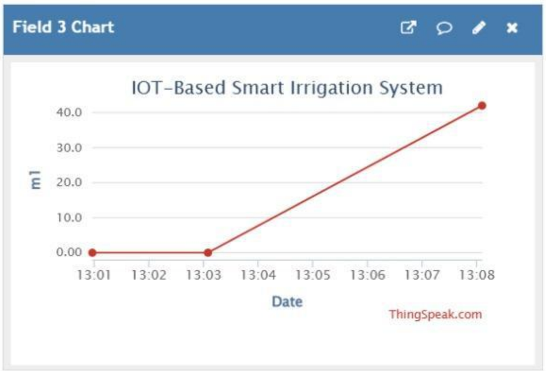


Fig. 8 Field 3: Moisture Sensor 1

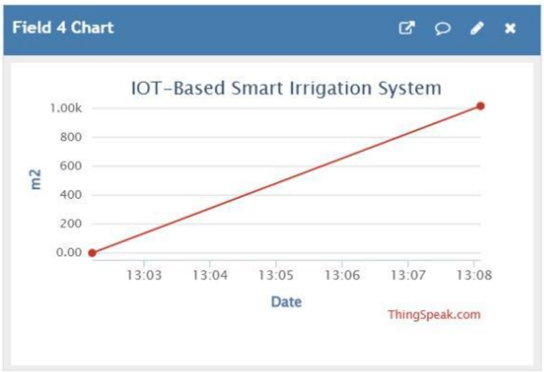


Fig. 9 Field 4: Moisture Sensor 2

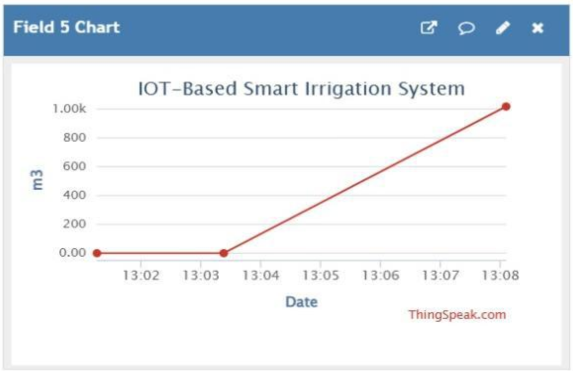


Fig. 10 Field 5: Moisture Sensor 3

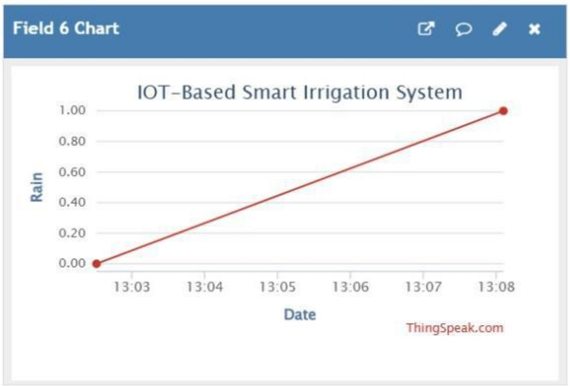


Fig. 11 Field 6: Rain Sensor

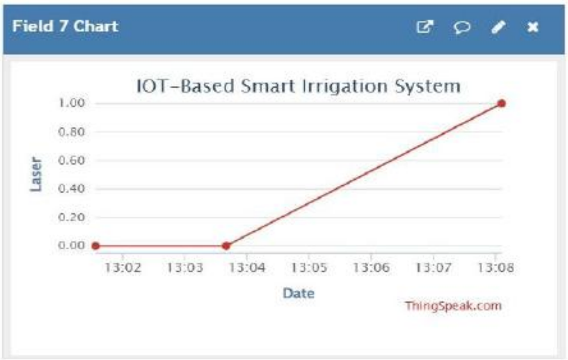


Fig. 12 Field 7: Laser Sensor

The results of the environmental monitoring and control system were successfully recorded and analyzed using the ThingSpeak IoT platform. The system utilized multiple sensors to measure environmental parameters such as temperature, humidity, soil moisture levels, rain detection, and intruder detection**.** The data collected from these sensors was transmitted to the ThingSpeak platform via the ESP8266 module for real-time visualization and analysis. The graphical representation of the sensor data on ThingSpeak provided valuable insights into the system's performance and environmental conditions.

The results are presented in a series of graphs which display the trends and variations in the collected data over time. Each field on the ThingSpeak platform corresponds to a specific sensor parameter**.** *Fig.6* shows that in field 1, the *temperature* readings showed consistent variations throughout the monitoring period, reflecting environmental changes. The graph highlights the system's ability to accurately track temperature fluctuations. *Fig.7* shows that in field 2, *humidity* levels were recorded and displayed, demonstrating the system's capability to monitor atmospheric moisture effectively. *Fig.8,9 and 10* shows that in fields 3, 4, and 5, the *soil moisture* levels at three different locations were monitored. The graphs indicate when irrigation was triggered based on predefined thresholds. For instance, when soil moisture dropped below 500 units, the corresponding solenoid valve was activated to irrigate that specific area. *Fig.11* shows that in field 6 , *rain* events were detected using the rain sensor, with corresponding data points logged on ThingSpeak. This feature allowed the system to bypass irrigation during rainy conditions. *Fig.12* shows that in field 7, *intruder* alerts were logged whenever the laser sensor detected movement. This functionality ensures security in agricultural or greenhouse environments.

The ThingSpeak platform provided a centralized interface for monitoring all sensor data in real time, enabling remote access and analysis of environmental conditions. This integration not only facilitated efficient irrigation management but also ensured optimal resource utilization by preventing overwatering during rain or when sufficient soil moisture was detected.

The results demonstrate that the proposed IoT-based smart irrigation system is highly effective in automating environmental monitoring and control processes. The results highlight the significance of IoT-based systems in automating irrigation processes while conserving resources and improving agricultural productivity**[5].** The accurate detection of sensor data and its seamless transmission to ThingSpeak highlight the reliability and scalability of this system for smart agriculture applications.

V. CONCLUSION

The IoT-based Smart Irrigation System is a significant step toward modernizing agriculture by integrating advanced technologies to address traditional irrigation challenges. This project demonstrates the potential of IoT to revolutionize farming practices, ensuring efficient use of water and other resources, improving crop yields, and reducing manual labour. The system optimizes water usage by monitoring real-time soil moisture levels and environmental conditions. By automating the irrigation process, it prevents over-irrigation and under-irrigation, contributing to sustainable water management. Automating irrigation reduces labour costs and minimizes water and energy wastage, offering long-term economic benefits for farmers, especially in water-scarce regions. By conserving water and reducing resource wastage, the project aligns with global efforts toward sustainable farming and addresses critical issues like water scarcity and climate change.

REFERENCES

[1] A. Rawal, "IoT-based smart irrigation system," International Journal of Computer Applications, vol. 159, no. 8, pp. 7-11, Feb. 2017. [Online]. Available: https://www.researchgate.net/publication/313779760_IOT_based_Smart_Irrigation_System

[2] L. García, L. Parra, J. M. Jimenez, J. Lloret, and P. Lorenz, "IoT-based smart irrigation systems: An overview on the recent trends on sensors and IoT systems for irrigation in precision agriculture," Sensors, vol. 20, no. 4, p. 1042, Feb. 2020. DOI: 10.3390/s20041042. [Online]. Available: https://www.mdpi.com/1424-8220/20/4/1042

[3] S. K. Ghosh, R. Dubey, and A. K. Sinha, "An IoT based smart irrigation management system using machine learning and open source technologies," in Proc. 2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), Vancouver, BC, Canada, 2018, pp. 978-983. DOI: 10.1109/IEMCON.2018.8614881. [Online]. Available: https://www.researchgate.net/publication/328758849_An_IoT_based_smart_irrigation_management_system_using_Machine_learning_and_open_source_technologies

[4] A. K. Tripathy, S. K. Mohanty, and S. K. Patra, "IoT and machine learning approaches for automation of farm irrigation system," in Proc. 2020 International Conference on Computer Science, Engineering and Applications (ICCSEA), Gunupur, India, 2020, pp. 1-5. DOI: 10.1109/ICCSEA49143.2020.9132927. [Online]. Available: https://www.researchgate.net/publication/340705747_IoT_and_Machine_Learning_Approaches_for_Automation_of_Farm_Irrigation_System

[5] M. R. Islam, M. A. Hossain, and M. S. Rahman, "Towards irrigation automation based on dielectric soil sensors," The Journal of Horticultural Science and Biotechnology, vol. 96, no. 3, pp. 319-329, May 2021. DOI: 10.1080/14620316.2021.1906761. [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/14620316.2021.1906761

[6] M. S. Islam, M. A. Hossain, and M. S. Rahman, "IoT-IIRS: Internet of Things based intelligent-irrigation recommendation system," Computers and Electronics in Agriculture, vol. 185, p. 106138, May 2021. DOI: 10.1016/j.compag.2021.106138. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8237332/

[7] S. K. Ghosh, R. Dubey, and A. K. Sinha, "Internet of Things-based automated solutions utilizing machine learning for smart irrigation: A systematic review," Agronomy, vol. 11, no. 9, p. 1805, Sep. 2021. DOI: 10.3390/agronomy11091805. [Online]. Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC11644754/

[8] M. R. Islam, M. A. Hossain, and M. S. Rahman, "IoT-based smart irrigation management system to enhance water use efficiency," ScienceDirect, 2024. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S2590123024010843

[9] T. Ahmadi Pargo, M. Akbarpour Shirazi, and D. Fadai, "IoT and cloud-based sustainable smart irrigation system," E3S Web of Conferences, 2024. [Online]. Available: https://www.e3s-conferences.org/articles/e3sconf/pdf/2024/02/e3sconf_icregcsd2023_01026.pdf

[10] X. Zhang, Y. Wang, and L. Chen, "EEWMP: An IoT-based energy-efficient water management platform for precision agriculture," Wiley Online Library, 2021. [Online]. Available: https://onlinelibrary.wiley.com/doi/10.1155/2021/5536884