International Journal for Modern Trends in Science and Technology
Volume 12, Special Issue 01, pages 1068-1074.
ISSN: 2455-3778 online
Available online at: http://ijmtst.com/ICRCSET2026.html
DOI: https://doi.org/10.5281/zenodo.19613577

Machine learning Powered IOT Greenhouse Climate Automation System for Temperature, Humidity & soil moisture

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To Cite this Article
Koya Haritha, B. Tejaswini, A. Pujitha, G. Bhanu Prakash & L. Manikanta (2026). Machine learning Powered IOT Greenhouse Climate Automation System for Temperature, Humidity & soil moisture. International Journal for Modern Trends in Science and Technology, 12(SI01), 1068-1074. https://doi.org/10.5281/zenodo.19613577

Article Info
Received: 12 March 2026; Revised: 07 April 2026; Accepted: 10 April 2026.

KEYWORDS

Internet of things (IoT), smart agriculture, greenhouse monitoring, Arduino, ESP8266, soil moisture sensor, DHT11 SENSOR.

ABSTRACT

In recent years, smart agriculture has gained significant attention as a solution to improve crop productivity and optimize resource utilization. This paper presents an IoT-based greenhouse monitoring and control system using Arduino, ESP8266 Wi-Fi module, DHT11 sensor, soil moisture sensor, and I2C LCD display. The system continuously monitors environmental parameters such as temperature, humidity, and soil moisture inside a greenhouse. The Arduino processes sensor data and executes control operations based on predefined threshold values to maintain optimal conditions for plant growth. The ESP8266 module enables wireless communication, allowing real-time data transmission to an IoT platform for remote monitoring. The system automatically controls irrigation by activating a water pump when soil moisture falls below a set threshold. The proposed system reduces manual intervention, improves water efficiency, and ensures better crop health. Experimental results show that the system effectively maintains environmental stability, making it a cost-effective and scalable solution for smart agriculture.

I. INTRODUCTION

Agriculture is one of the most essential sectors for sustaining human life, yet it faces major challenges such as inefficient water usage, lack of real-time monitoring, and dependence on manual labor. Traditional farming methods often fail to maintain optimal environmental conditions, which can lead to reduced crop yield and resource wastage. In particular, improper irrigation practices and the absence of continuous monitoring of temperature, humidity, and soil moisture significantly affect plant growth and productivity.

With the rapid advancement of Internet of Things (IoT) technology, modern agriculture is transitioning toward smart and automated systems. IoT enables real-time data acquisition, remote monitoring, and intelligent decision-making, which helps improve efficiency and reduce human intervention. Embedded systems such as Arduino, along with wireless communication modules like ESP8266, have made it possible to develop low-cost and scalable smart farming solutions.

In addition to IoT, Machine Learning (ML) techniques are increasingly being integrated into smart agriculture systems to enhance decision-making capabilities. Machine learning algorithms can analyze historical sensor data to predict soil moisture levels, environmental changes, and irrigation requirements. This predictive capability allows the system to move beyond simple threshold-based automation toward intelligent and adaptive control. By learning patterns from environmental conditions, ML models can optimize water usage, improve crop health prediction, and reduce resource wastage more efficiently.

This paper presents an IoT-based smart greenhouse monitoring and control system integrated with machine learning concepts for improved automation. The system uses sensors for temperature, humidity, and soil moisture, combined with an Arduino microcontroller and ESP8266 Wi-Fi module for real-time monitoring and communication. The proposed approach enhances agricultural productivity by combining IoT-based automation with data-driven intelligence, enabling both real-time control and predictive analysis for sustainable farming.

II. REVIEW LITERATURE SURVEY

The development of IoT-based smart agriculture systems has gained significant attention due to the increasing demand for efficient resource utilization and automated farming techniques. Various researchers have proposed different frameworks using embedded systems, sensors, and wireless communication technologies for monitoring and controlling agricultural environments.

Mishra et al. (2021) proposed an IoT-based smart agriculture monitoring and automatic irrigation system using ESP8266. The system integrates soil moisture, temperature, and humidity sensors to automate irrigation based on environmental conditions. Their study concluded that the system significantly reduces water wastage by ensuring irrigation only when required.

Kumar and Singh (2020) designed a smart greenhouse monitoring system using Arduino and IoT technologies. The system collects real-time environmental data and transmits it to a cloud platform for remote monitoring. The authors emphasized that IoT-based solutions improve precision farming and reduce manual intervention.

Patel et al. (2022) developed a low-cost IoT-based greenhouse monitoring system using NodeMCU (ESP8266) and DHT11 sensors. The system enables real-time monitoring of temperature and humidity and provides automated control of irrigation systems. Their results showed improved efficiency in water management and crop maintenance.

Sharma and Verma (2021) implemented a cloud-based smart irrigation system using ThingSpeak IoT platform. The system allows real-time visualization of sensor data and remote control of irrigation devices. The authors highlighted that cloud integration enhances accessibility and decision-making in agricultural systems.

Zhang et al. (2023) explored the integration of Machine Learning with IoT-based smart agriculture systems. Their study demonstrated that machine learning models can analyze historical environmental data to predict soil moisture levels and optimize irrigation scheduling. This approach improves accuracy and reduces dependency on fixed threshold-based systems.

From the literature, it is observed that most existing systems utilize microcontrollers such as Arduino and ESP8266 along with sensors like DHT11 and soil moisture sensors. While these systems effectively automate irrigation and monitoring, they largely depend on predefined thresholds. Recent advancements suggest that integrating Machine Learning techniques can enhance prediction accuracy and enable more intelligent decision-making in smart agriculture systems

III. RESEARCH METHODOLOGY

The proposed IoT-based smart greenhouse system is designed to monitor and control environmental parameters such as temperature, humidity, and soil moisture using Arduino and ESP8266. The methodology followed in this work focuses on data acquisition, processing, decision-making, and actuation to maintain optimal conditions for plant growth. The system also supports IoT connectivity for remote monitoring and future enhancement using machine learning-based prediction.

A. System Design Approach

The system is designed using a modular approach consisting of sensing unit, processing unit, communication unit, and actuation unit. The sensing unit collects real-time environmental data, while the processing unit (Arduino UNO) analyzes the data. The ESP8266 module enables wireless communication, and the actuation unit controls irrigation and environmental regulation devices.

B. Data Acquisition

Environmental parameters are continuously measured using:

- DHT11 sensor for temperature and humidity
- Soil moisture sensor for measuring water content in soil

The sensors provide analog and digital signals to the Arduino microcontroller for processing.

C. Data Processing and Decision Logic

The Arduino UNO processes the sensor data and compares it with predefined threshold values. The decision-making process is based on simple rule-based logic:

- If soil moisture is below a defined threshold → irrigation system is activated
- If temperature exceeds a certain limit → cooling fan is activated (optional)
- If conditions are normal → all actuators remain OFF

This ensures real-time control of greenhouse conditions.

D. Communication and IoT Integration

The ESP8266 Wi-Fi module is used to transmit sensor data to an IoT cloud platform. This enables remote monitoring of environmental parameters through mobile or web applications. The system ensures continuous data logging and accessibility from anywhere.

E. Actuation System

The actuation unit consists of a relay module connected to:

- Water pump for irrigation control
- Fan or cooling system for temperature regulation

The relay is controlled by Arduino based on decision logic.

F. Machine Learning Integration (Proposed Enhancement)

To improve system intelligence, machine learning techniques can be integrated in future development. Historical sensor data can be used to train predictive models that estimate soil moisture levels and environmental changes. This allows the system to move beyond fixed threshold-based decisions toward predictive and adaptive control, improving water efficiency and crop yield.

G. Flow of Methodology

1. Sensors collect environmental data
2. Data is sent to Arduino for processing
3. Decision logic evaluates conditions
4. Actuators are triggered if required
5. ESP8266 transmits data to IoT platform
6. User monitors system remotely

IV. PROPOSED METHODOLOGY

The proposed IoT-based smart greenhouse monitoring and control system is designed to automate environmental regulation and improve resource efficiency in agricultural applications. The system follows a closed-loop control approach in which real-time environmental data is continuously collected, processed, and used for decision-making to maintain optimal conditions for plant growth. It integrates sensing, processing, communication, and actuation units using Arduino and ESP8266, making the system both efficient and scalable for modern smart agriculture.

In the proposed system, environmental parameters such as temperature, humidity, and soil moisture are continuously monitored using sensors. The DHT11 sensor is used to measure temperature and humidity, while a soil moisture sensor is used to determine the water content in the soil. These sensor readings are sent to the Arduino UNO microcontroller, which acts as the central processing unit of the system. The microcontroller processes the incoming data and evaluates it based on predefined threshold values.

Based on the decision logic implemented in the Arduino, appropriate control actions are performed. If the soil moisture level falls below a defined threshold, the irrigation system is automatically activated using a relay-controlled water pump. Similarly, if the temperature exceeds a specified limit, a cooling fan can be activated to maintain suitable environmental conditions. When all parameters are within the desired range, the system remains inactive, ensuring energy efficiency.

For communication and remote monitoring, the ESP8266 Wi-Fi module is used to transmit real-time sensor data to an IoT cloud platform. This allows users to monitor greenhouse conditions remotely using a mobile or web application. Additionally, an I2C LCD display is used for local visualization of environmental parameters, providing real-time feedback within the greenhouse.

Furthermore, the proposed system can be enhanced using machine learning techniques in future developments. By analyzing historical sensor data, machine learning models can predict environmental changes and soil moisture requirements, enabling proactive irrigation and smarter decision-making. This transforms the system from a simple rule-based automation model into an intelligent, adaptive agricultural solution.

BLOCK DIAGRAM

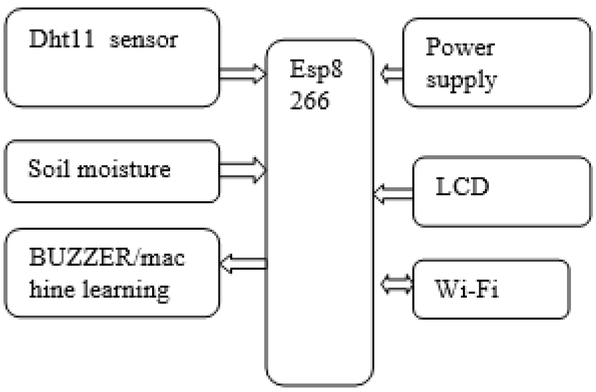

Fig. 4.1. Block Diagram

V. RESULTS AND OUTCOMES

The implemented IoT-based smart greenhouse monitoring and control system successfully demonstrates real-time monitoring and automation of environmental parameters such as temperature, humidity, and soil moisture. The integration of Arduino UNO, ESP8266 Wi-Fi module, DHT11 sensor, and soil moisture sensor enables continuous data acquisition and efficient decision-making for greenhouse management.

During system testing, the sensors provided stable and consistent readings of environmental conditions. The DHT11 sensor effectively measured temperature and humidity variations, while the soil moisture sensor accurately detected the water content in the soil. Based on the threshold values programmed in the microcontroller, the system successfully automated irrigation by activating the water pump whenever soil moisture levels dropped below the required limit. Similarly, temperature variations were monitored to maintain a suitable environment for plant growth.

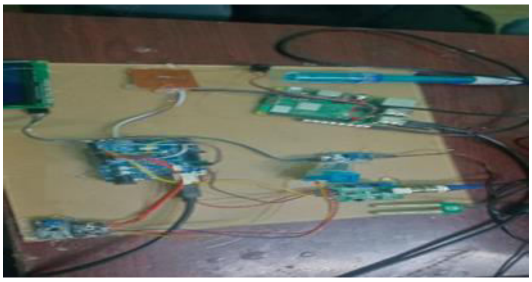

Fig. 5.1. Output1

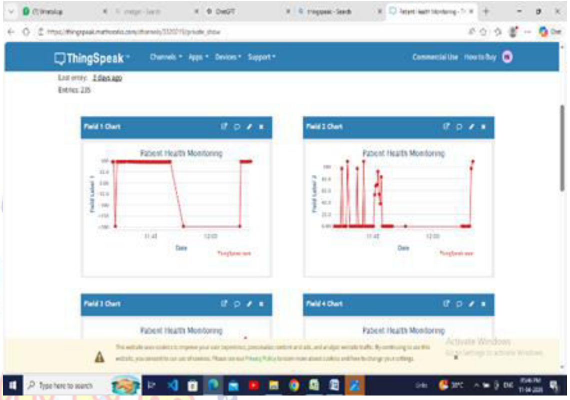

Fig. 5.2. Output2

The ESP8266 module enabled seamless wireless communication, allowing real-time data to be transmitted to an IoT platform. This feature allowed users to remotely monitor greenhouse conditions through a mobile or web interface. Additionally, the I2C LCD display provided continuous local visualization of environmental parameters, improving system usability and accessibility.

The overall system performance showed that automation significantly reduces manual intervention and improves water usage efficiency. The irrigation system operated only when necessary, thereby preventing water wastage. The results indicate that the proposed system is reliable, cost-effective, and suitable for small-scale greenhouse applications

VI. CONCLUSION

The proposed IoT-based smart greenhouse monitoring and control system provides an efficient and low-cost solution for modern agricultural automation. By integrating Arduino UNO, ESP8266 Wi-Fi module, DHT11 sensor, and soil moisture sensor, the system successfully monitors critical environmental parameters such as temperature, humidity, and soil moisture in real time. The automation logic ensures that irrigation and environmental control are performed only when required, thereby improving resource utilization and reducing manual intervention.

The implementation of IoT technology enables remote monitoring and control of greenhouse conditions through cloud connectivity, making the system more flexible and user-friendly. The inclusion of an I2C LCD display further enhances local monitoring capabilities by providing real-time environmental data.

The experimental results demonstrate that the system effectively maintains optimal conditions for plant growth while significantly reducing water wastage and human effort. This makes the proposed system a reliable and scalable solution for precision agriculture and smart farming applications.

Furthermore, the system can be enhanced in future work by integrating Machine Learning algorithms to enable predictive analysis of environmental conditions. This would allow the system to move beyond rule-based automation toward intelligent decision-making, improving irrigation scheduling and overall agricultural efficiency

Overall, the system contributes significantly to improving flood preparedness and public safety. With further enhancements such as machine learning-based prediction models and integration of additional environmental sensors, the system can be made even more accurate and robust in future implementations.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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