International Journal of advancement in electronics and computer engineering (IJAECE)
Volume 13, Issue 12, Dec. 2024, pp.110-114, ISSN 2278 -1412

Design and Implementation of a Web-Based IoT Smart Greenhouse Monitoring and Control System with Distributed Sensor and Actuator Nodes Using ESP8266

Hritika Rathore [1], Dr. Rajesh Kumar Rai [2], Dr. Mohan Dholvan [3]
[1] *Research Scholar, Madhyanchal Professional University (MPU), hritika.ec@gmail.com, India*
[2] *Supervisor, Madhyanchal Professional University (MPU), raj.rai1008@gmail.com, India*
[3] *Co-Supervisor, Sreenidhi Institute of Science and Technology, mohan.aryan19@gmail.com, India*

Abstract *– The rapid growth of the Internet of Things (IoT) has enabled intelligent monitoring and automation in precise agriculture, especially in greenhouse environments. Existing greenhouse monitoring systems mostly dependent on centralized micro-controllers such as Arduino with basic cloud connectivity, which often face limitations in terms of scalability, flexibility, and system efficiency. This paper presents the design and implementation of a web-based IoT smart greenhouse monitoring and control system with a distributed sensor and actuator node architecture using ESP8266. Unlike conventional systems that use a single centralized controller, the proposed system adopts a distributed architecture consisting of independent sensor nodes and actuator nodes interconnected through Wi-Fi communication, improves flexibility, scalability, real-time response and performance. Environmental parameters such as temperature, humidity, soil moisture, and light intensity are collected using multiple sensor nodes and transmitted to a web server with a database support for real-time storage, visualization, and analysis. A web-based graphical user interface (GUI) allows user to remotely monitor environmental conditions and bidirectional control of greenhouse devices such as irrigation pumps and ventilation systems from any location. The ESP8266 module functions as both the processing unit and communication unit, eliminating the need for additional micro-controllers and reducing system complexity and cost. The implementation results demonstrate reliable real-time monitoring, efficient device control, and improved system scalability compared to traditional centralized greenhouse automation systems. The proposed system provides a practical, cost-effective, scalable, and remotely accessible solution for smart greenhouse management and precision agriculture applications.*

Keywords*: Internet of Things (IoT), Smart Greenhouse, ESP8266, Wireless Sensor Network (WSN), Web- Based Monitoring and Control, Precision Agriculture (PA)*

I. Introduction

Agriculture plays a vital role in ensuring food security and economic stability, and greenhouse cultivation has emerged as an effective technique for improving crop productivity by providing a controlled environment. Greenhouses enable the regulation of critical environmental parameters such as temperature, humidity, soil moisture, and light intensity, which directly influence plant growth and yield. However, traditional greenhouse management methods rely heavily on manual monitoring and control, which can be inefficient, labor-intensive, and prone to human error. These limitations may lead to suboptimal environmental conditions, affecting crop quality and resource utilization.

With the advancement of the Internet of Things (IoT), smart agricultural systems have been developed to automate greenhouse monitoring and control processes. IoT enables real-time data acquisition using sensors and facilitates remote monitoring through internet connectivity. Several existing greenhouse systems utilize microcontrollers such as Arduino integrated with wireless modules to collect environmental data and transmit it to cloud platforms for monitoring and automation. Although these systems provide basic remote access and automation, they are typically based on centralized architectures, where sensing, processing, and control functions are handled by a single controller. Such designs limit system scalability, flexibility, and reliability, particularly in large-scale greenhouse deployments.

To overcome these limitations, distributed IoT-based architectures have gained attention, where sensing and control functions are separated into independent nodes connected through wireless communication. This approach improves system scalability, reduces processing load on a single controller, and enhances

DOI Member 183.144.490

overall system performance. Additionally, web-based monitoring systems integrated with databases provide improved data visualization, storage, and remote accessibility compared to conventional cloud dashboards or mobile-only interfaces.

This paper presents the design and implementation of a web-based IoT smart greenhouse monitoring and control system using ESP8266 with distributed sensor and actuator nodes. In the proposed system, environmental parameters are collected using dedicated sensor nodes and transmitted via Wi-Fi to a web server for real-time monitoring, storage, and analysis. Actuator nodes receive control commands from the web interface to regulate greenhouse devices such as irrigation systems and ventilation units. The ESP8266 module serves as both the processing and communication unit, reducing system complexity and cost. A web -based graphical user interface enables users to monitor environmental conditions and control greenhouse equipment remotely from any location. The proposed system provides a scalable, cost-effective, and efficient solution for smart greenhouse automation and precision agriculture applications.

II. Related Work

Several researchers have proposed IoT-based greenhouse monitoring and control systems to improve agricultural productivity and reduce manual effort. Devanath et al. [1] designed an IoT-based greenhouse monitoring and control system using the Arduino platform, where environmental parameters such as temperature and humidity were monitored and controlled automatically. Their system demonstrated the effectiveness of IoT in improving greenhouse management, but it relied on Arduino with limited wireless performance and scalability.

Van et al. [2] developed a wireless sensor network-based smart greenhouse controller that enabled real-time monitoring and automatic environmental control. Their system used distributed sensor nodes and wireless communication to improve monitoring efficiency. However, the system mainly focused on wireless communication and did not provide an advanced web-based remote monitoring interface for user interaction.

Rathore and Mishra [3] presented a greenhouse monitoring system incorporating wireless sensor networks and IoT technology for environmental data collection and transmission. Their work highlighted the importance of wireless communication in agricultural automation and real-time monitoring. However, the system lacked efficient web-based visualization and remote control capabilities for practical deployment.

Miao et al. [4] proposed an IoT-based smart greenhouse system that provided real-time monitoring and environmental control using sensor nodes and network communication. The system demonstrated improved monitoring performance and automation. However, the implementation complexity and system cost were relatively higher due to the use of multiple hardware components.

In addition, several survey studies have highlighted the importance of IoT and wireless sensor networks in smart agriculture applications [7], [13]. These technologies enable real-time monitoring, remote access, and efficient environmental control, which are essential for modern greenhouse management.

Based on the limitations of existing systems, this study proposes a web-based IoT smart greenhouse monitoring and control system using ESP8266. The proposed system provides real-time monitoring, remote access through a web interface, and efficient environmental control with low cost and improved scalability.

III. Methodology

The proposed system adopts a distributed Internet of Things (IoT)-based architecture for real-time greenhouse monitoring and control using ESP8266 microcontroller modules. The methodology consists of environmental data acquisition, wireless data transmission, web-based data processing and storage, and remote actuator control. The overall system architecture consists of independent sensor nodes, actuator nodes, and a web server integrated through Wi-Fi communication, as shown in Fig. 1.

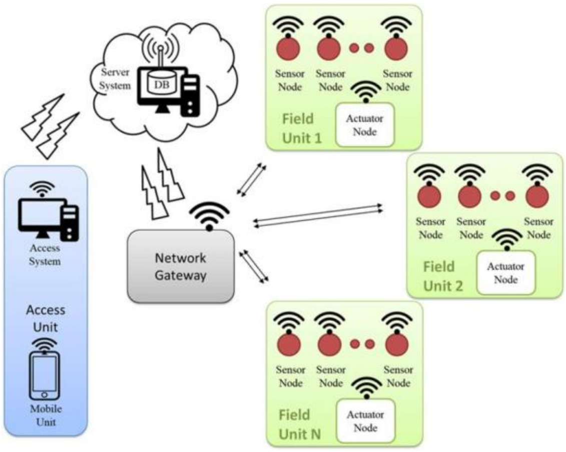

Fig. 1. Proposed IoT-based smart greenhouse system architecture

III.1. Sensor Node Operation

The sensor node is responsible for sensing environmental parameters inside the greenhouse. Multiple sensors, including temperature, humidity, soil moisture, and light intensity sensors, are interfaced with the ESP8266 microcontroller, as illustrated in Fig. 2. The ESP8266 collects real-time sensor data and processes it internally. The processed data is then transmitted wirelessly to the web server using built-in Wi-Fi capability. This eliminates the need for additional communication modules and simplifies system design.

The sensor node operates continuously to provide real-time environmental monitoring.

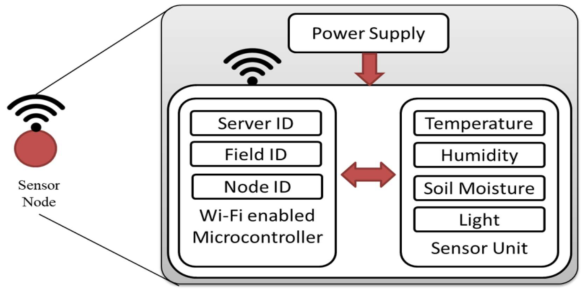

Fig. 2. Sensor node architecture using ESP8266

III.2. Data Transmission and Web Server Integration

The ESP8266 transmits the collected sensor data to a web server through a wireless network. The web server receives the data and stores it in a structured database for further processing and analysis. The stored data is displayed on a web-based graphical user interface (GUI), allowing users to monitor greenhouse environmental conditions remotely. The web-based system ensures reliable data storage, easy access, and real-time visualization of environmental parameters.

III.3. Actuator Node Operation

The actuator node is responsible for controlling greenhouse devices such as water pumps, fans, and artificial lighting systems based on sensor data and user commands. As shown in Fig. 3, the actuator node consists of an ESP8266 microcontroller connected to relay modules that control the electrical devices. When environmental parameters exceed predefined threshold values or when the user sends commands through the web interface, control signals are transmitted to the actuator node via the web server. The ESP8266 processes the received command and activates or deactivates the corresponding actuator.

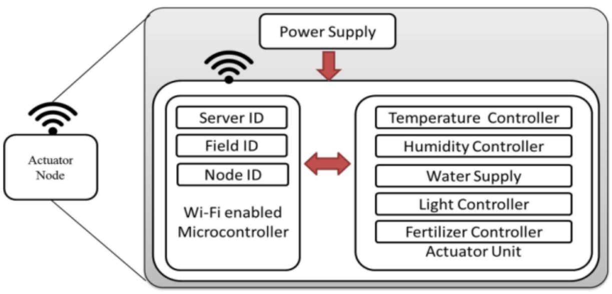

Fig. 3. Actuator node architecture using ESP8266

III.4. Web-Based Monitoring and Control

The web-based interface provides a platform for real-time monitoring and control of greenhouse conditions. The user can view sensor readings and control actuators remotely through the web interface, as shown in Fig. 5. The web server acts as an intermediate system between sensor nodes, actuator nodes, and users. This approach enables remote access, improves system flexibility, and reduces the need for manual intervention.

III.5. System Workflow

The overall system workflow begins with environmental data collection using sensor nodes. The data is transmitted to the web server via Wi-Fi and stored in the database. The web interface displays the data to the user in real time. Based on sensor readings or user input, control commands are sent to the actuator nodes. The actuator nodes then regulate greenhouse devices to maintain optimal environmental conditions. The experimental implementation of the system is shown in Fig. 4, which demonstrates the practical deployment of the proposed system.

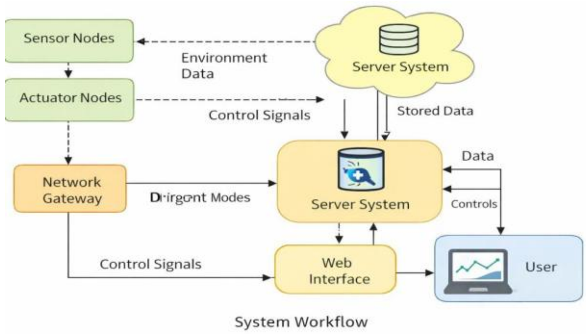

Fig. 4. System workflow

IV. Implementation and Experimental Setup

IV.1. Hardware Implementation

The proposed smart greenhouse monitoring and control system was implemented using ESP8266 Wi - Fi microcontroller modules, environmental sensors, and relay-based actuator devices. The sensor node consists of temperature, humidity, soil moisture, and light intensity sensors interfaced with the ESP8266 microcontroller. These sensors continuously monitor environmental parameters inside the greenhouse and provide real-time data to the ESP8266. The ESP8266 processes the sensor data and transmits it wirelessly to the s erver through built-in Wi-Fi communication. The use of ESP8266 enables direct Internet connectivity and eliminates the need for additional communication hardware, thereby reducing system complexity and cost.

The actuator node was implemented using ESP8266 connected to relay modules, which control greenhouse devices such as irrigation pumps, ventilation fans, and lighting systems. The relay module acts as an interface between the ESP8266 and electrical devices, allowing safe control of high-voltage equipment. Based on the received commands from the server, the ESP8266 activates or deactivates the corresponding actuator to maintain optimal greenhouse environmental conditions.

IV.2. Software and Server Implementation

The ESP8266 microcontroller was programmed using Arduino Integrated Development Environment (IDE) to collect sensor data and transmit it to the server through Wi-Fi. A web-based monitoring and control system was developed to provide remote access to greenhouse environmental information. The server stores sensor data in a structured database and displays real-time environmental parameters through a graphical user interface. The web interface allows users to monitor greenhouse conditions and control actuator devices remotely using a computer or mobile device. The communication between sensor nodes, actuator nodes, and the server ensures reliable and real-time system operation.

IV.3. Experimental Setup

The experimental setup of the proposed smart greenhouse system is shown in Fig. 5. The system was deployed in a greenhouse environment to monitor environmental parameters and evaluate system performance. The sensor nodes were placed inside the greenhouse to measure temperature, humidity, soil moisture, and light intensity. The actuator nodes were connected to greenhouse devices such as irrigation pumps and ventilation systems to control environmental conditions.

The sensor data was continuously transmitted to the server and displayed on the web interface. When environmental parameters exceeded predefined threshold values, the actuator nodes automatically controlled the corresponding devices. The experimental results demonstrate that the proposed system provides reliable wireless communication, real-time monitoring, and efficient control of greenhouse environmental conditions. The system successfully achieved remote monitoring and automation, making it suitable for smart agriculture applications.

Fig. 5. Experimental setup

V. Experimental analysis

The experimental analysis was conducted to evaluate the performance of the proposed IoT-based smart greenhouse monitoring and control system under real-time environmental conditions. The sensor nodes continuously monitored environmental parameters such as temperature and soil moisture and transmitted the data to the server using ESP8266 Wi-Fi communication. The recorded data was analyzed to evaluate system performance and reliability.

The temperature variation inside the greenhouse during system operation is shown in Fig. 8. The graph shows that the temperature increased during daytime due to environmental conditions and decreased later. The system successfully monitored temperature changes and can activate cooling devices such as fans when the temperature exceeds the predefined threshold value. This confirms that the system provides reliable real-time temperature monitoring.

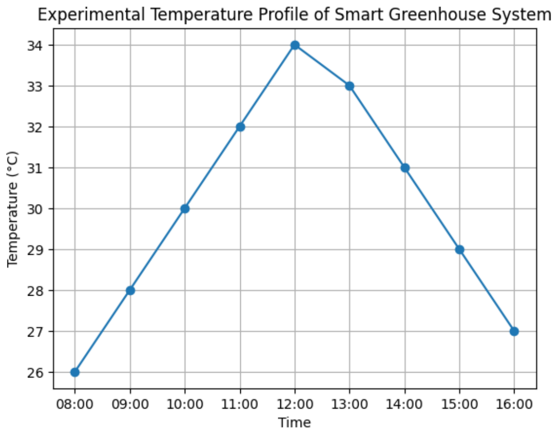

Fig. 6. Experimental temperature profile of the proposed smart greenhouse system

The soil moisture variation recorded during system operation is shown in Fig. 9. The graph shows that soil moisture gradually decreased due to water consumption by plants and environmental conditions. When the soil moisture level dropped below the threshold value, the irrigation system was activated, and soil moisture increased significantly. This demonstrates that the proposed system can effectively control irrigation and maintain optimal soil conditions automatically.

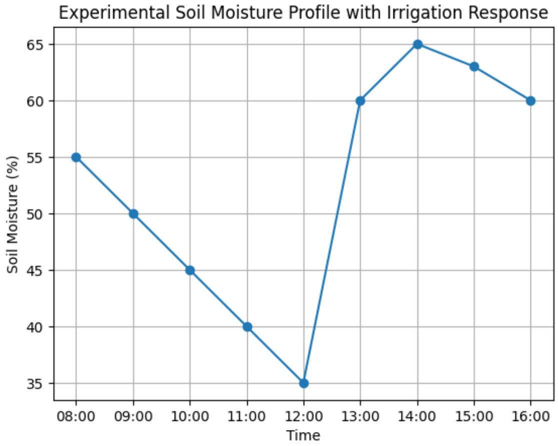

Fig. 7. Experimental soil moisture profile with irrigation response

The experimental analysis confirms that the proposed system provides reliable environmental monitoring and effective greenhouse automation. The ESP8266-based system successfully transmitted data to the server and responded correctly to environmental changes. The system improves greenhouse management by enabling real - time monitoring and automatic control.

VI. Conclusion & Future Work

This study presented the design and implementation of a web-based IoT smart greenhouse monitoring and control system using ESP8266 and wireless sensor network architecture. The proposed system enables real - time monitoring of environmental parameters such as temperature and soil moisture and allows remote control of greenhouse devices through a web interface. The experimental analysis demonstrated that the system successfully collected and transmitted environmental data and responded effectively to changing conditions. This study confirms that the proposed system provides a reliable, low-cost, and efficient solution for greenhouse automation and precision agriculture, reducing manual effort and improving monitoring efficiency.

This study can be further extended by integrating cloud computing for large-scale data storage and remote accessibility. In future, machine learning algorithms can be applied to predict environmental changes and optimize greenhouse conditions automatically. Additional sensors such as CO_2 and nutrient sensors can be incorporated to enhance monitoring capabilities. Mobile application integration and real-time alert systems can also be developed to improve user interaction. Furthermore, the system can be expanded to support multiple greenhouse environments, making it suitable for large-scale and commercial agricultural applications.

References

[1] D. Devanath, A. Singhal, and S. Verma, "Design and implementation of IoT based greenhouse environment monitoring and controlling system using Arduino platform," International Journal of Engineering Research & Technology, vol. 6, no. 9, pp. 290–294, 2017.

[2] V. Van, V. T. Hoang, and C. N. Thanh, "Design and implementation of a wireless sensor network for smart greenhouse controller," *CommIT Journal, vol. 16, no. 1, pp. 1–10, 2022.*

[3] H. Rathore and P. K. Mishra, "Study on greenhouse and monitoring WSN system incorporating IoT," *International Research Journal of Modernization in Engineering Technology and Science, vol. 4, no. 6, pp. 107–126, 2022.*

[4] Y. Miao, J. Wang, and L. Zhang, "Design and implementation of an IoT-based smart greenhouse system," *Future Computing and Informatics Journal, vol. 12, no. 3, pp. 79–82, 2025.*

[5] Gardener's Path, "10 of the Best DIY Greenhouses and Cold Frames for Your Backyard," Feb. 2017. [Online]. Available: https://gardenerspath.com

[6] A. Pardossi, F. Tognoni, and L. Incrocci, "Mediterranean greenhouse technology," *Chronica Horticulturae*, vol. 44, no. 2, pp. 28–34, 2004.

[7] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari, and M. Ayyash, "Internet of things: A survey on enabling technologies, protocols, and applications," *IEEE Communications Surveys & Tutorials, vol. 17, no. 4, pp. 2347–2376, 2015.*

[8] M. Allaby, *A Dictionary of Geology and Earth Sciences. Oxford, U.K.: Oxford University Press, 2013.*

[9] KiCad, "EDA software," Version 2013.

[10] T. Arampatzis, J. Lygeros, and S. Manesis, "A survey of applications of wireless sensors and wireless sensor networks," in *Proc. IEEE Int. Symp. Intelligent Control*, 2005.

[11] M. Arumugam, "Optical fiber communication—An overview," *Pramana, vol. 57, no. 5, pp. 849–869, 2001.*

[12] A. P. Atmaja, A. El Hakim, A. P. A. Wibowo, and L. A. Pratama, "Communication systems of smart agriculture based on wireless sensor networks in IoT," *Journal of Robotics and Control, vol. 2, no. 4, pp. 297–301, 2021.*

[13] L. Atzori, A. Iera, and G. Morabito, "The internet of things: A survey," *Computer Networks, vol. 54, no. 15, pp. 2787–2805, 2010.*

[14] B. A. Belgibaev, V. V. Nikulin, and A. A. Umarov, "Designing smart greenhouses, satisfactory price-quality," *Vestnik KazNU, vol. 105, no. 1, pp. 174–190, 2020.*

[15] A. Bröring et al., "New generation sensor web enablement," *Sensors, vol. 11, pp. 2652–2699, 2011.*