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IoT-Based Greenhouse Monitoring and Controlling System

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ABSTRACT

Agriculture forms the backbone of human civilization, and the ability to cultivate crops in controlled environments has become increasingly vital in the face of climate change, land scarcity, and the growing global demand for food. This paper presents the design and implementation of an IoT-based Greenhouse Monitoring and Controlling System using the ESP32 microcontroller as its central processing unit. The system integrates a DHT11 sensor for ambient temperature and relative humidity measurement, a resistive soil moisture sensor, and a Light Dependent Resistor (LDR) module for ambient light intensity measurement. These sensors collectively provide a comprehensive real-time environmental profile of the greenhouse. The system incorporates intelligent threshold-based automation: when soil moisture drops below 30%, the water pump relay activates automatically; when temperature exceeds 30.8°C, the ventilation fan relay is triggered. A 16x2 I2C LCD display provides on-site visualization, while all sensor data are transmitted wirelessly to the ThingSpeak IoT cloud platform at 15-second intervals, enabling remote monitoring, historical data logging, and trend analysis. The proposed system demonstrates a low-cost, scalable, and energy-efficient approach to precision agriculture, targeted at small-to-medium scale greenhouse operations.

Keywords: *IoT, Greenhouse Automation, ESP32, DHT11, Soil Moisture, Smart Agriculture, Relay Control, Cloud Monitoring, ThingSpeak, Precision Farming.*

1. INTRODUCTION

Agriculture has always been the cornerstone of human survival and economic development. As the global population continues to surge toward an estimated 9.7 billion by 2050, the pressure on conventional farming systems to meet rising food demands has never been greater. Traditional open-field farming is increasingly vulnerable to unpredictable weather patterns, prolonged droughts, pest infestations, and soil degradation, all of which are being intensified by climate change. Greenhouse farming has emerged as one of the most promising responses to these challenges, offering a protected and regulated environment in which crops can be cultivated year-round, independent of seasonal fluctuations.

However, within a greenhouse, conditions such as temperature, humidity, soil moisture, and light intensity must be carefully maintained within specific optimal ranges. Traditional greenhouse management relies heavily on manual monitoring, which is labor-intensive, time-consuming, and often prone to human error. The advent of the Internet of Things (IoT) has fundamentally transformed how physical systems are monitored and controlled, enabling continuous data collection, remote monitoring, and automated decision-making without requiring constant physical presence on-site.

This paper proposes an integrated IoT-based greenhouse monitoring and controlling system built around the ESP32 microcontroller, which provides the computational power and built-in Wi-Fi connectivity necessary for the system. The system continuously measures four critical environmental parameters—temperature, humidity, soil moisture, and light intensity—and automates irrigation and ventilation in real time. Sensor data is transmitted to the ThingSpeak cloud platform for remote access and historical analysis.

2. LITERATURE REVIEW

A substantial body of research literature has emerged exploring IoT-based greenhouse management, precision irrigation, remote data acquisition, and smart farming systems. Early research in the area of greenhouse automation, predating widespread IoT adoption, focused primarily on standalone embedded systems and wired sensor networks using programmable logic controllers (PLCs). While demonstrating the fundamental principle that automated environmental control could significantly improve crop yields and reduce labor costs, these systems were characterized by high hardware costs, limited scalability, and the absence of remote monitoring capabilities.

The emergence of low-cost microcontroller platforms such as the Arduino and ESP8266/ESP32 fundamentally transformed IoT-based agricultural monitoring. Patil and Ade (2016) demonstrated an Arduino-based greenhouse monitoring system that used temperature, humidity, and soil moisture sensors to automate irrigation and ventilation in a small-scale greenhouse, reporting measurable improvements in water use efficiency and crop yield. Rajkumar et al. (2017) implemented a soil monitoring system for precision agriculture using ESP8266 and ThingSpeak, confirming the suitability of these platforms for cloud-integrated agricultural applications.

Gondchawar and Kawitkar (2016) proposed a comprehensive IoT framework for smart farming integrating sensor data acquisition, cloud storage, mobile application access, and automated device control in a unified architecture. Research by Maier et al. (2017) conducted a comparative evaluation of microcontroller platforms for IoT applications, concluding that the ESP32 offered the best balance of computational capability, connectivity features, and cost-effectiveness. Singh et al. (2019) validated the DHT11 sensor's reliability for greenhouse temperature and humidity monitoring, demonstrating sufficient precision for threshold-based automated control. Hu et al. (2018) developed an LDR-based light monitoring module for a smart greenhouse and demonstrated its practical utility for lighting management decisions. Shamshiri et al. (2018) confirmed that simple threshold-based automated control systems implemented on low-cost microcontroller platforms provided the greatest practical impact per unit of investment for small-scale greenhouse operators.

3. PROPOSED METHODOLOGY

3.1 System Architecture Overview

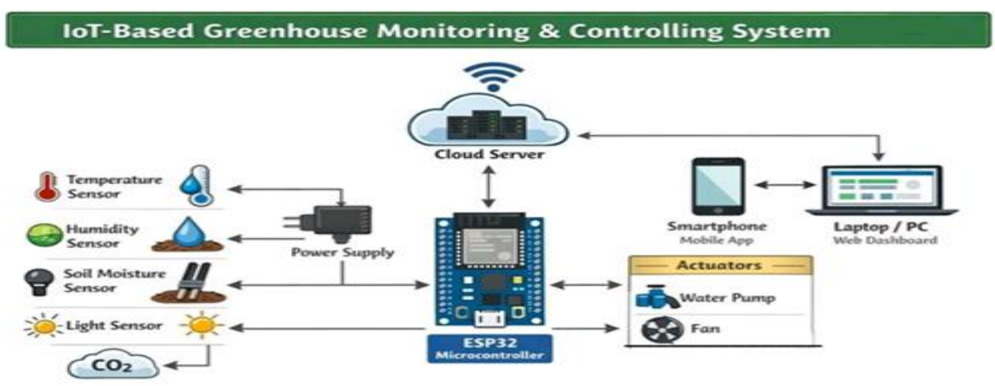

Fig 1. System Architecture

The proposed IoT-based greenhouse monitoring and controlling system is structured around a four-layer architecture: (1) the sensing layer, comprising multiple environmental sensors; (2) the processing layer, centered on the ESP32 microcontroller; (3) the local display layer, implemented via a 16x2 I2C LCD; and (4) the cloud connectivity layer, interfacing with the ThingSpeak IoT platform over Wi-Fi. The system is programmed using the Arduino IDE with the ESP32 board support package, enabling use of the extensive Arduino library ecosystem.

3.2 System Requirements and Threshold Specification

During the requirement analysis phase, the system was specified to monitor four key environmental parameters: ambient temperature, relative humidity, soil moisture content, and ambient light intensity, while controlling two actuator devices—a water pump for automated irrigation and a ventilation fan for temperature management. Threshold values were determined based on agronomic literature and standard greenhouse management guidelines:

- Soil moisture threshold: 30% (pump activates when moisture falls below this level)
- Temperature threshold: 30.8°C (fan activates when temperature exceeds this value)
- LCD update interval: every 2 seconds (alternating between two display screens)
- ThingSpeak data transmission interval: every 15 seconds (minimum permitted by the free tier)

3.3 Hardware Components

The following hardware components were selected based on cost-effectiveness, availability, ease of integration, and proven reliability in similar applications:

Component	Specification	Role in System
ESP32 Microcontroller	Dual-core 240 MHz, 12-bit ADC, Built-in Wi-Fi/Bluetooth	Central processing unit; sensor acquisition, decision logic, cloud communication
DHT11 Sensor	Temp: 0–50°C (±2°C), Humidity: 20–90% RH (±5%)	Measures ambient temperature and relative humidity
Soil Moisture Sensor	Resistive type, Analog output 0–3.3V	Monitors soil water content; controls irrigation pump
LDR Module	Analog voltage output, 0–100% mapped	Measures ambient light intensity inside greenhouse
16x2 I2C LCD	PCF8574 backpack, I2C address 0x27	Local real-time display for on-site operators
Pump Relay Module	Active-low, 5V, Optoisolated	Controls water pump for automated irrigation
Fan Relay Module	Active-low, 5V, Optoisolated	Controls ventilation fan for temperature management
Power Supply Unit	5V USB adapter, 1–2A	Powers entire system via USB input

3.4 GPIO Pin Allocation

GPIO pins were allocated as follows: GPIO 4 for DHT11 data line; GPIO 34 as analog input for soil moisture sensor; GPIO 35 as analog input for LDR module; GPIO 25 as digital output for pump relay control; GPIO 26 as digital output for fan relay control; GPIO 21 (SDA) and GPIO 22 (SCL) for I2C LCD communication.

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3.5 Software Architecture

The firmware is structured around a modular architecture with clearly separated functions: a setup() function handling hardware initialization; a main loop() orchestrating timing and sequencing; a readSensors() function for sequential sensor data acquisition; a controlDevices() function implementing threshold-based automation logic; an updateLCD() function managing the alternating display mode; and a sendToThingSpeak() function constructing and transmitting HTTP GET requests to the cloud platform. The system employs active-low relay logic (relay activated when GPIO is driven LOW) as a safety measure, ensuring actuators remain off during power-up and reset events.

3.6 Cloud Integration: ThingSpeak Platform

ThingSpeak is a cloud-based IoT analytics platform developed by MathWorks that provides data storage, visualization, and analysis services. The ESP32 transmits six distinct data fields to ThingSpeak every 15 seconds via HTTP GET requests: temperature (Field 1), humidity (Field 2), soil moisture (Field 3), light level (Field 4), pump relay status (Field 5), and fan relay status (Field 6). The platform provides automatic graph generation for each data field, enabling remote monitoring and historical trend analysis from any internet-connected device.

4. RESULTS AND DISCUSSION

4.1 System Performance

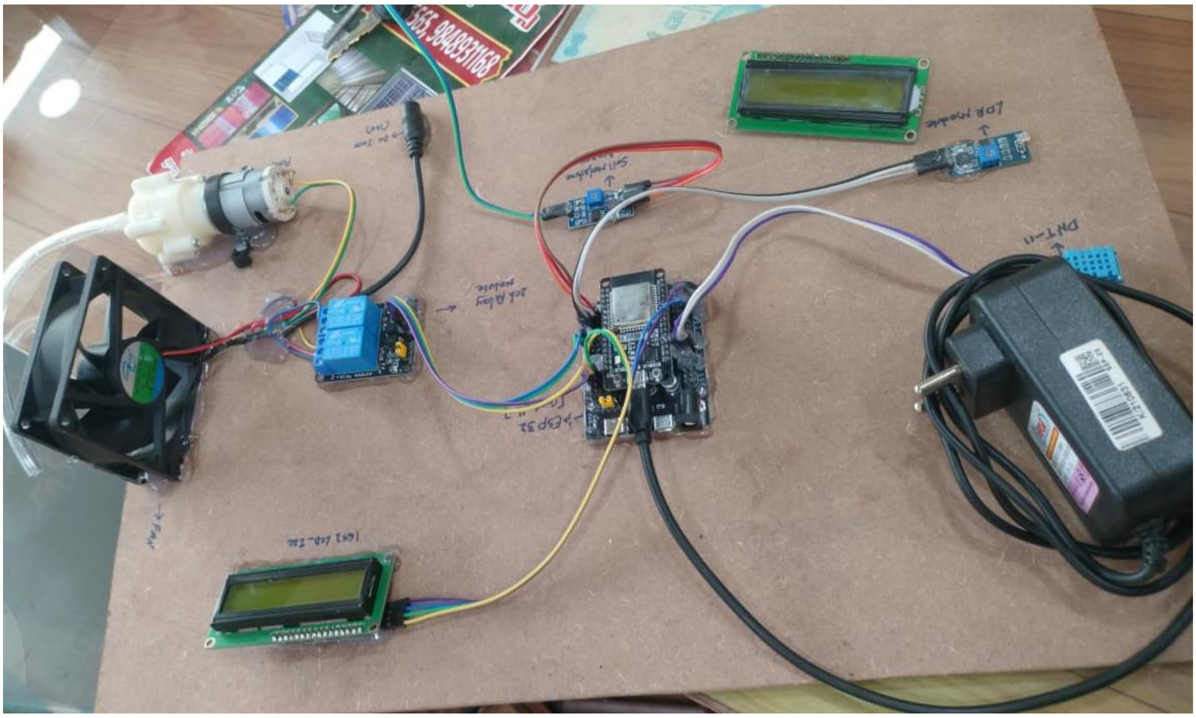

Fig 2. Hardware Device

The implemented system was deployed and tested under realistic greenhouse-simulated conditions. All hardware components were assembled on a breadboard prototype and validated through component-level and integrated system testing. The following results were observed:

- Sensor Accuracy: DHT11 temperature readings validated against a reference thermometer showed accuracy within the specified ±2°C tolerance. Humidity readings were within ±5% RH as specified.

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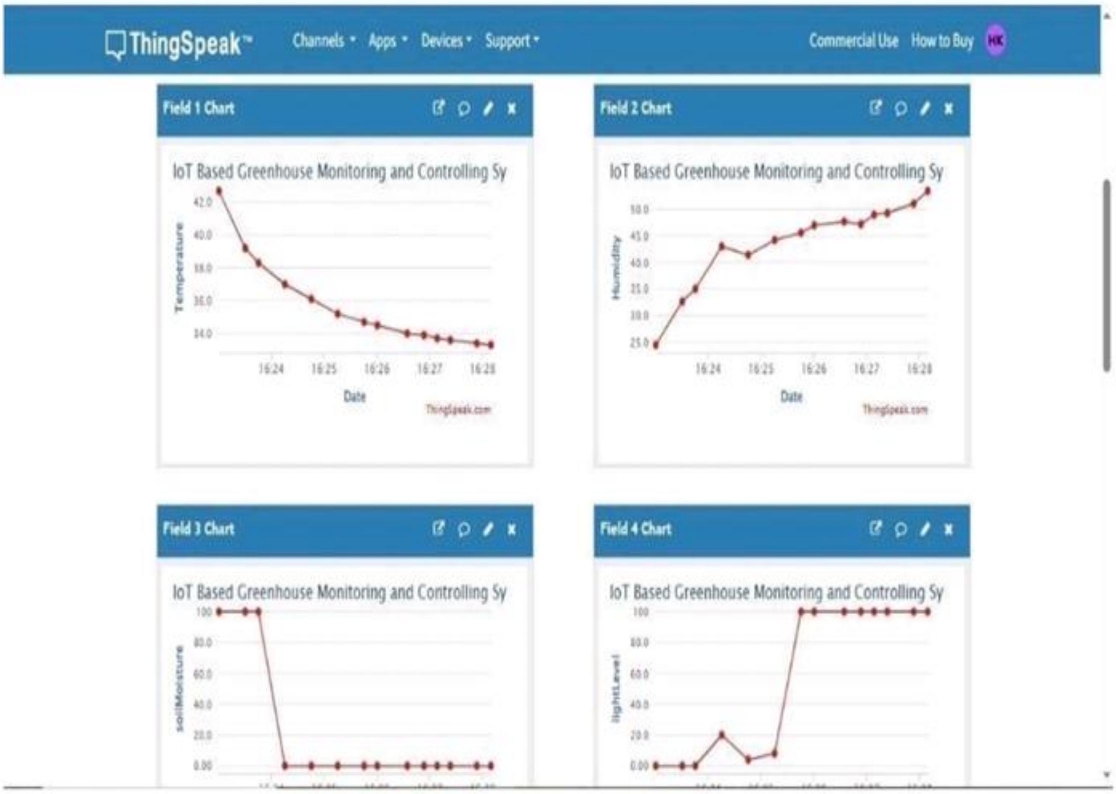
- Soil Moisture Automation: The pump relay responded correctly to soil moisture values below the 30% threshold in all test cycles. Irrigation stopped automatically when moisture was restored above threshold, preventing overwatering.
- Ventilation Automation: The fan relay activated reliably whenever the DHT11-measured temperature exceeded 30.8°C and deactivated when temperature returned below the threshold.
- LCD Display: The 16x2 LCD alternated correctly between the temperature/humidity screen and the soil moisture/light level screen at 2-second intervals.
- ThingSpeak Data Transmission: All six data fields appeared on the ThingSpeak dashboard at the expected 15-second intervals with correct values for all parameters including pump and fan relay status.
- Wi-Fi Reliability: The automatic reconnection logic successfully re-established Wi-Fi connectivity after simulated network outages without requiring a system restart.

4.2 ThingSpeak Dashboard Observations



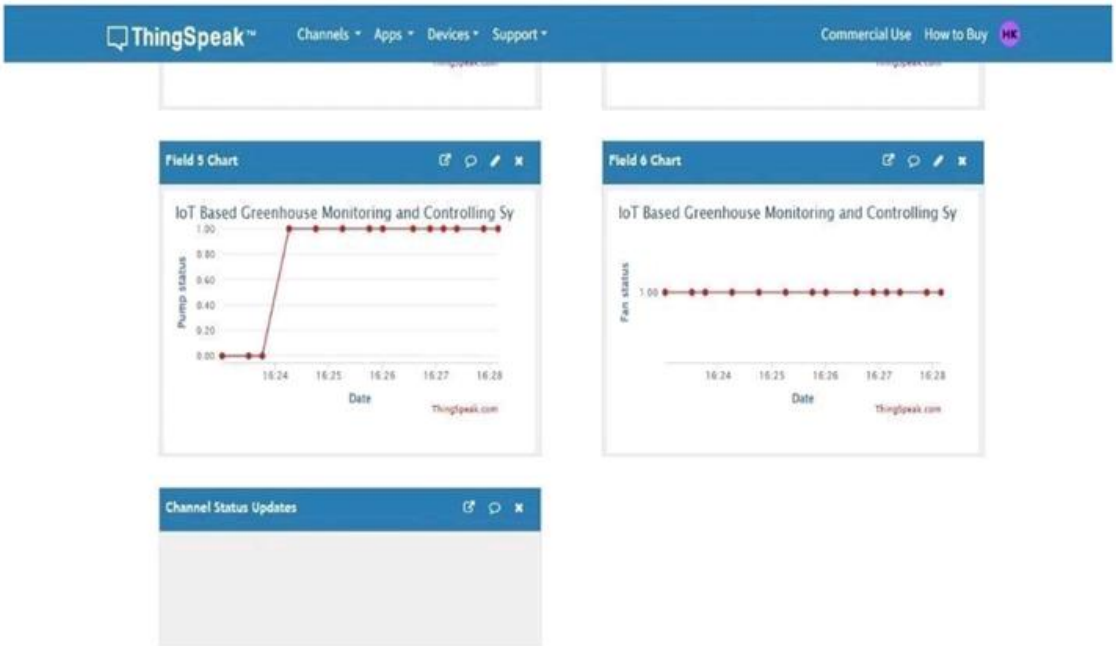


Fig 3. IoT Platform Results

Time-series charts on the ThingSpeak dashboard clearly visualized environmental trends. Temperature readings ranged between 34–42°C during testing, triggering fan activation consistently above the 30.8°C threshold. Humidity varied between 25–50% RH, reflecting changes in the test environment. Soil moisture readings showed clear step-wise increases during simulated irrigation events. Light level readings spanned the full 0–100% range in response to varying ambient light conditions during testing. Pump status (Field 5) and fan status (Field 6) charts confirmed binary switching behavior correlated with the respective sensor thresholds.

4.3 Advantages of the Proposed System

The system offers the following key advantages over conventional manual greenhouse management:

- Real-time continuous monitoring eliminates the detection delays associated with periodic manual inspection.
- Automated threshold-based control removes the need for round-the-clock human supervision.
- Cloud-based remote access allows farm managers to monitor and verify system status from any location worldwide.
- Historical data logging supports evidence-based decision-making and identification of recurring environmental patterns.
- Low-cost, commercially available components make the system economically accessible to small and medium-scale greenhouse operators.
- Modular and scalable architecture allows straightforward expansion with additional sensors, relay channels, or multiple greenhouse zones.
- Energy-efficient operation with a total system power budget well within a standard 1–2 A USB power adapter.

5. FUTURE SCOPE

While the current implementation successfully achieves its defined objectives, several directions exist for future enhancement:

- Expansion to a multi-node wireless sensor network architecture deploying multiple ESP32 nodes across different greenhouse zones to address spatial variability in environmental conditions.
- Integration of higher-accuracy sensors such as the DHT22 or BME280 (for temperature, humidity, and barometric pressure) and capacitive soil moisture

sensors for improved measurement precision.

- Incorporation of machine learning algorithms to analyze historical ThingSpeak data and predict future environmental conditions, enabling proactive rather than reactive control strategies.
- Implementation of an automated alert and notification system that sends real-time SMS, email, or mobile push notifications when critical threshold conditions are detected.
- Integration of solar power generation and rechargeable battery backup to make the system energetically self-sufficient for remote greenhouse deployments.
- Development of a dedicated mobile application for enhanced user interaction, custom threshold configuration, and push notification management.
- Addition of CO2 and pH monitoring sensors to provide a more comprehensive agronomic data profile.

6. CONCLUSION

This paper has presented the design, implementation, and validation of a low-cost, scalable, and fully functional IoT-based greenhouse monitoring and controlling system. The system successfully integrates the ESP32 microcontroller, DHT11 temperature and humidity sensor, resistive soil moisture sensor, and LDR light sensor to provide continuous real-time monitoring of four critical environmental parameters. Intelligent threshold-based automation maintains soil moisture and temperature within optimal ranges without human intervention, while the ThingSpeak cloud platform enables remote monitoring and historical data analysis from any internet-connected device.

The implementation demonstrates that high-impact agricultural automation is achievable using affordable, commercially available components guided by sound engineering principles. By addressing the fundamental limitations of conventional manual greenhouse management—inadequate real-time monitoring, reactive rather than proactive environmental control, imprecise irrigation, and the absence of remote access and data logging—this system provides a practical, replicable, and extensible foundation for the broader adoption of smart farming technologies. The project contributes a coherent reference model for students, researchers, and agricultural technology developers working in the field of precision farming and IoT-enabled agriculture.

REFERENCES

[1] Gondchawar, N., & Kawitkar, R. S. (2016). IoT based smart agriculture. International Journal of Advanced Research in Computer and Communication Engineering, 5(6), 838–842.

[2] Patil, S. S., & Ade, R. (2016). An IoT based smart greenhouse monitoring and controlling system using Arduino. International Journal of Innovative Research in Computer and Communication Engineering, 4(2), 1702–1708.

[3] Rajkumar, M. N., Abinaya, S., & Kumar, V. S. (2017). Intelligent irrigation system using IoT. International Conference on Innovations in Green Energy and Healthcare Technologies, 1–5.

[4] Maier, A., Sharp, A., & Vagapov, Y. (2017). Comparative analysis and practical implementation of the ESP32 microcontroller for IoT applications. 25th International Conference on Systems Engineering, 1–5.

[5] Singh, R., Srivastava, P., & Ojha, P. (2019). IoT based greenhouse monitoring and controlling system. International Journal of Engineering and Advanced Technology, 8(6), 1539–1544.

[6] Hu, Y., Zhao, W., & Li, X. (2018). Light intensity monitoring and control system for greenhouse based on IoT technology. Journal of Agricultural Mechanization Research, 40(3), 212–217.

[7] Shamshiri, R. R., et al. (2018). Advances in greenhouse automation and controlled environment agriculture. International Journal of Agricultural and Biological Engineering, 11(1), 1–22.

[8] Mehra, M., et al. (2018). IoT based hydroponics system using deep neural networks. Computers and Electronics in Agriculture, 155, 473–486.

[9] Bwire, C., & Jang, J. W. (2019). Microcontroller based automated irrigation system using ESP32 and soil moisture sensor. International Journal of Advanced Computer Science and Applications, 10(8), 99–105.

INTERNATIONAL JOURNAL OF APPLIED SCIENCE ENGINEERING AND MANAGEMENT

ISSN2454-9940www.ijsem.org

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[10] Talavera, J. M., et al. (2017). Review of IoT applications in agro-industrial and environmental fields. Computers and Electronics in Agriculture, 142, 283–297.

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