SMART AGRICULTURE: RASPBERRY PI–BASED GREENHOUSE MONITORING AND AUTOMATION SYSTEM

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ABSTRACT
Greenhouse cultivation requires continuous monitoring and regulation of environmental parameters to maintain suitable conditions for plant growth. Conventional greenhouse management commonly depends on manual observation, which can be labour-intensive and may result in delayed responses to environmental variations. This paper presents a Raspberry Pi-based smart greenhouse monitoring and automation system that integrates environmental sensing, embedded processing, wireless communication, cloud monitoring, and automated actuator control. A DHT22 sensor is employed to monitor temperature and relative humidity, a soil-moisture sensor is used to assess soil-water conditions, and an LDR-based sensor is used to monitor light intensity. Raspberry Pi functions as the central controller and IoT gateway, acquiring sensor measurements and comparing them with predefined operating thresholds. Based on the measured conditions, a water pump is activated when the soil becomes dry, an exhaust fan is operated when the temperature exceeds the desired limit, and a grow light is activated when illumination becomes insufficient. The acquired environmental data are transmitted through Wi-Fi to the ThingSpeak cloud platform for remote monitoring and alert generation. The proposed system integrates sensing, decision-making, actuation, and cloud connectivity into a compact and economical greenhouse automation platform. The documented experimental operation demonstrates automatic irrigation, temperature-based ventilation, light-based illumination control, and remote environmental monitoring. The architecture is suitable for small-scale greenhouse cultivation, polyhouse farming, nursery management, research farms, and educational smart-agriculture applications.

Keywords: Smart agriculture, greenhouse automation, Raspberry Pi, Internet of Things, soil moisture, DHT22, LDR, ThingSpeak, automated irrigation, environmental monitoring.

I. INTRODUCTION

Agriculture is increasingly adopting digital technologies to improve productivity, resource utilization, and environmental management. Greenhouse cultivation provides a controlled environment in which important parameters such as temperature, humidity, soil moisture, and light intensity can be monitored and regulated. Maintaining these parameters within appropriate ranges is essential for healthy crop development. However, conventional greenhouse management frequently relies on periodic manual inspection, which requires continuous human involvement and may not respond rapidly to changing environmental conditions. The Internet of Things (IoT) provides an effective approach for addressing these limitations by enabling physical parameters to be continuously measured and communicated to processing and monitoring platforms. IoT-based agricultural systems combine sensors, embedded controllers, communication networks, cloud platforms, and actuators to create automated monitoring and control environments [1]–[5]. The development of low-cost embedded platforms has further simplified the implementation of smart agriculture systems. Raspberry Pi provides processing capability, connectivity, and hardware interfaces within a compact platform. It can therefore serve as both a local controller and an IoT gateway for greenhouse applications. This work presents a Raspberry Pi-based greenhouse monitoring and automation system integrating three major environmental sensing functions: temperature and humidity monitoring, soil-moisture monitoring, and light-intensity monitoring. The system uses a DHT22 sensor for temperature and humidity, a soil-moisture

Doi:10.48047/ijiee.2026.16.2.62

sensor for irrigation decisions, and an LDR/light sensor for illumination monitoring. The Raspberry Pi processes the sensor measurements and controls three actuators through relay modules: a water pump, an exhaust fan, and a grow light. The system follows a threshold-based control strategy. When the soil moisture falls below the predefined operating condition, irrigation is activated. When the temperature becomes high, the exhaust fan is switched ON. When the available light becomes insufficient, the grow light is activated. Sensor measurements are also transmitted through Wi-Fi to the ThingSpeak cloud platform, allowing remote monitoring and alert generation.

The major contributions of the proposed system are:

1. Development of an integrated Raspberry Pi-based greenhouse monitoring platform.
2. Continuous monitoring of temperature, humidity, soil moisture, and light intensity.
3. Development of a low-cost architecture suitable for small-scale and experimental greenhouse applications.

II. RELATED WORK

IoT has become an important technological foundation for smart agriculture because it enables physical agricultural parameters to be monitored continuously. A typical agricultural IoT architecture consists of sensing devices, processing units, communication networks, cloud services, and user interfaces. Sensors collect information from the agricultural environment, embedded controllers process the measurements, communication networks transfer information to remote platforms, and actuators execute control decisions. Such systems can reduce manual intervention and improve the timeliness of agricultural management. Previous studies have investigated IoT-based agricultural systems for environmental monitoring, irrigation management, crop monitoring, and agricultural automation [2], [3]. Wireless sensor networks have also been investigated for distributed agricultural monitoring, particularly where multiple measurement locations are required.

Greenhouse cultivation requires continuous observation of environmental parameters because plant development is sensitive to temperature, humidity, soil-water availability, and illumination. Li *et al.* reviewed IoT-based greenhouse monitoring approaches and identified environmental sensing, communication, and information-processing systems as major components of intelligent greenhouse architectures [6]. Temperature and humidity influence plant physiological processes and greenhouse microclimate. Soil moisture is directly related to irrigation requirements, while light intensity affects photosynthetic activity and plant development. Consequently, monitoring these parameters provides important information for greenhouse management. The proposed system focuses on these four environmental parameters and integrates them into a single embedded monitoring and control architecture.

Soil-moisture monitoring is widely used in automated irrigation systems. Instead of applying water according to a fixed schedule, an automated system can activate irrigation when soil conditions indicate insufficient moisture. The proposed system implements this concept using a soil-moisture sensor connected to Raspberry Pi. When the measured soil condition indicates that the soil is dry, the Raspberry Pi activates the water pump through a relay module. This approach can reduce unnecessary manual irrigation and provides a simple mechanism for responding to changes in soil-water conditions.

Temperature control is another important aspect of greenhouse automation. Excessive temperature can adversely affect crop development. The proposed system therefore uses the DHT22 sensor to continuously monitor temperature and activates an exhaust fan when the temperature exceeds the predefined operating condition. Similarly, light intensity is measured using an LDR/light sensor. When the available illumination becomes insufficient, the Raspberry Pi activates a grow light.

Existing greenhouse monitoring systems range from simple sensor-monitoring platforms to advanced intelligent systems involving cloud computing, machine learning, robotics, and predictive control. Although advanced systems provide substantial capabilities, they can also introduce higher implementation complexity, computational requirements, and deployment costs. There remains a practical requirement for compact and economical systems that integrate

Doi:10.48047/ijiee.2026.16.2.62

sensing, local processing, automatic actuation, wireless communication, and remote monitoring in a single platform. The proposed system addresses this practical requirement by combining DHT22, soil-moisture, and LDR sensors with Raspberry Pi, relay-controlled actuators, Wi-Fi connectivity, and ThingSpeak cloud monitoring. The system intentionally uses threshold-based control, making it computationally simple and suitable for prototype-scale greenhouse deployment.

III. PROPOSED SYSTEM

The proposed greenhouse automation system consists of four principal layers namely sensing layer, Processing and decision layer, Actuation layer, and IoT/cloud monitoring layer. The sensing layer consists of the DHT22, soil-moisture, and LDR sensors. The processing layer is implemented using Raspberry Pi. It receives sensor measurements, evaluates the environmental conditions, and generates actuator-control decisions. The actuation layer consists of relay modules connected to the water pump, exhaust fan, and grow light. The communication layer uses Wi-Fi to transmit environmental measurements to ThingSpeak for cloud-based visualization and monitoring.

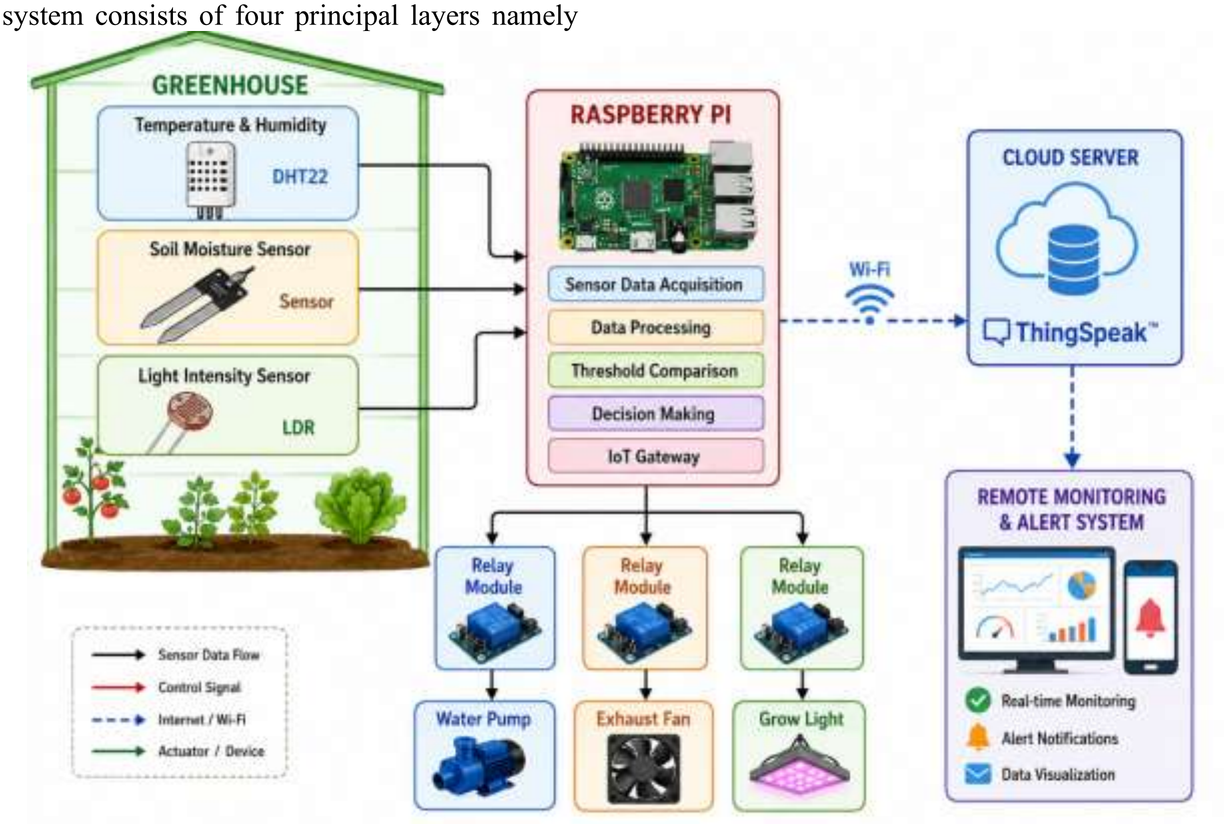

Figure 1: Block Diagram of Proposed System

The DHT22 sensor provides measurements of temperature and relative humidity inside the greenhouse.

Temperature information is used primarily for ventilation control, whereas humidity information is monitored as part of the greenhouse environmental condition. The soil-moisture sensor measures the water condition of the soil surrounding the plants.When the soil becomes sufficiently dry according to the predefined operating threshold, Raspberry Pi activates the water pump through the relay module.An LDR/light sensor is used to monitor illumination inside the greenhouse.When the available light becomes insufficient, Raspberry Pi activates the grow light to provide additional illumination.

IV. HARDWARE AND SOFTWARE IMPLEMENTATION

Raspberry Pi functions as the central controller and IoT gateway. It receives data from the environmental sensors and performs local processing and decision-making. The Raspberry Pi performs the following operations such as

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Sensor initialization, Environmental data acquisition, Threshold comparison, Actuator control, Wi-Fi communication, Cloud-data transmission and Continuous system operation.

Relay modules provide the interface between the Raspberry Pi and the external actuators. The relay outputs control Water pump, Exhaust fan and Grow light. The relays allow the low-power control signals generated by Raspberry Pi to operate the connected external devices. The water pump is used for automatic irrigation. When soil moisture falls below the predefined threshold, the Raspberry Pi sends a control signal to the corresponding relay and the pump is activated. When adequate soil moisture is detected, the pump remains OFF. The exhaust fan provides temperature-based ventilation. When the greenhouse temperature exceeds the selected operating threshold, Raspberry Pi activates the fan through the relay module. The fan remains OFF when the temperature is within the desired operating range. The grow light provides artificial illumination when natural or available greenhouse light is insufficient. The LDR measures the available light and Raspberry Pi compares the measured condition with the predefined threshold. If the light level is low, the grow light is switched ON.

Wi-Fi provides communication between Raspberry Pi and the cloud platform. The system uploads environmental measurements to ThingSpeak, where the data can be stored and visualized through a remote dashboard. This enables users to observe greenhouse conditions without being physically present at the greenhouse.

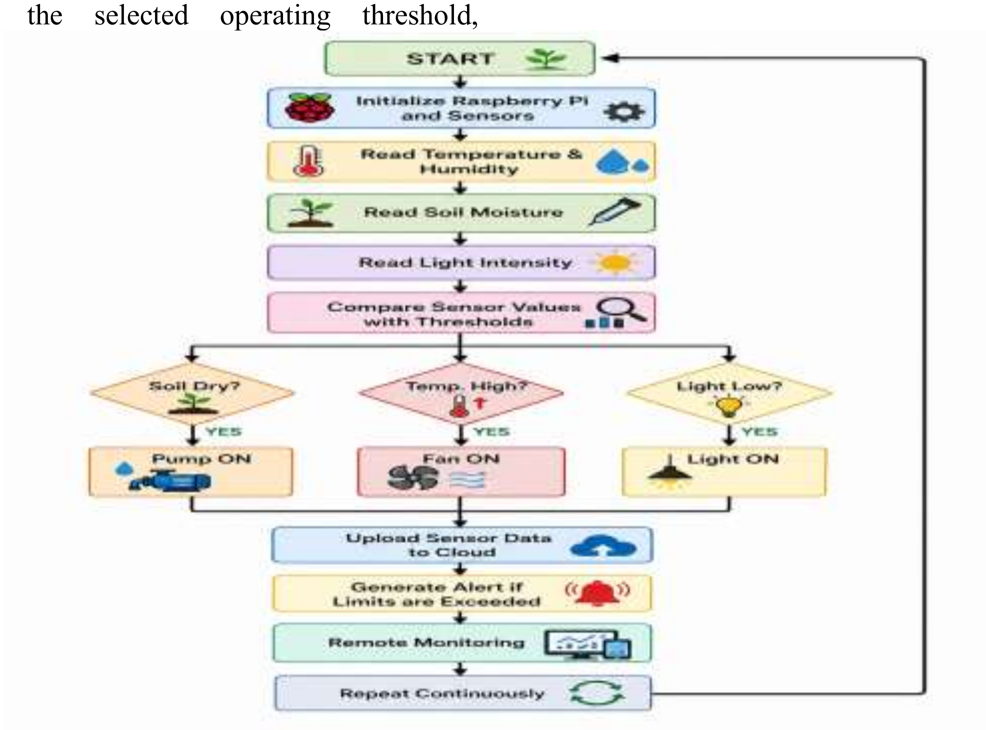

Figure 2: Flowchart of proposed system

Algorithm

Step 1: System Initialization

Raspberry Pi, DHT22, soil-moisture sensor, LDR, relay modules, and communication interfaces are initialized.

Step 2: Sensor Acquisition

The DHT22 measures temperature and humidity. The soil-moisture sensor measures soil-water conditions, and the LDR measures light intensity.

Step 3: Local Processing

Raspberry Pi receives the sensor measurements and compares them with predefined operating thresholds.

Step 4: Irrigation Control

If the soil is dry, the water pump is activated. Otherwise, the pump remains OFF.

Step 5: Temperature Control

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If the temperature exceeds the desired limit, the exhaust fan is activated. Otherwise, the fan remains OFF.

Step 6: Lighting Control

If the measured light intensity is insufficient, the grow light is activated. Otherwise, the grow light remains OFF.

Step 7: Cloud Transmission

The measured sensor information is transmitted through Wi-Fi to ThingSpeak.

Step 8: Alert Generation

If a monitored environmental parameter exceeds its specified operating range, an alert can be generated.

Step 9: Remote Monitoring

The user can access the cloud dashboard to observe current and historical environmental conditions.

Step 10: Continuous Operation

The complete sensing, decision-making, actuation, and cloud-monitoring process is repeated continuously.

V. RESULTS AND DISCUSSION

Overall Functional Results

Parameter	Sensor	Controlled Device	System Response
Temperature	DHT22	Exhaust fan	Fan activated under high-temperature condition
Humidity	DHT22	Monitoring	Humidity continuously monitored
Soil moisture	Soil-moisture sensor	Water pump	Pump activated under dry-soil condition
Light intensity	LDR	Grow light	Grow light activated under low-light condition
Cloud monitoring	Wi-Fi + ThingSpeak	Remote dashboard	Sensor information uploaded to cloud
Abnormal condition	Environmental sensors	Alert	Alert generated when limits are exceeded

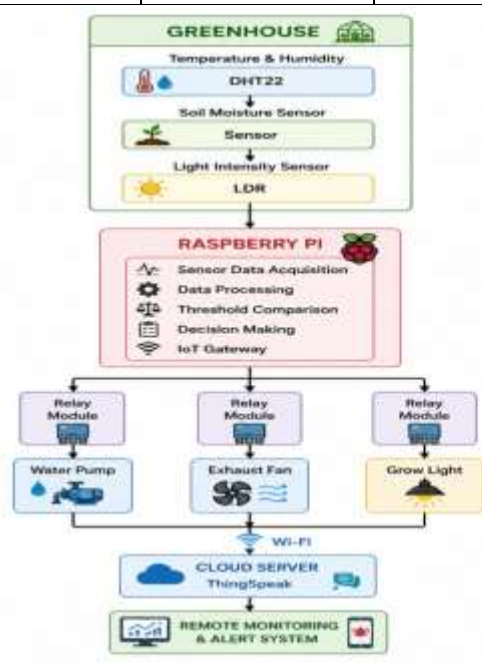

Figure 3: Results

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Figure 4 Experimental output

The developed system demonstrates the feasibility of integrating low-cost environmental sensors with Raspberry Pi for greenhouse monitoring and automation. A key feature of the proposed system is the integration of sensing and actuation. Instead of merely displaying sensor values, the Raspberry Pi uses the measured conditions to initiate physical actions. Soil-moisture information controls irrigation, temperature information controls ventilation, and light information controls artificial illumination. The threshold-based strategy is computationally simple and therefore appropriate for an embedded controller. It does not require a high-performance computing platform or complex training process. This makes the architecture suitable for prototype-scale and small greenhouse deployments. Cloud connectivity provides an additional layer of functionality. Local control decisions can be made directly by Raspberry Pi, while sensor information can simultaneously be transmitted to ThingSpeak for remote monitoring.

VI. CONCLUSION

This paper presented a Raspberry Pi-based smart greenhouse monitoring and automation system integrating environmental sensing, embedded processing, automated actuation, wireless communication, and cloud monitoring. The system uses DHT22, soil-moisture, and LDR sensors to monitor temperature, humidity, soil-water conditions, and light intensity. Raspberry Pi acts as the central controller and IoT gateway. The measured environmental conditions are processed locally and compared with predefined operating thresholds. Based on these conditions, the water pump is activated for dry soil, the exhaust fan is activated under high-temperature conditions, and the grow light is activated when illumination becomes insufficient. The integration of Wi-Fi and ThingSpeak enables remote monitoring of greenhouse conditions and supports alert generation. The system therefore combines continuous sensing with automatic physical control, reducing the need for constant manual intervention. The documented experimental operation demonstrates the feasibility of automatic irrigation, temperature-based ventilation, artificial lighting control, and cloud-based environmental monitoring. The architecture is particularly suitable for small-scale greenhouse cultivation, polyhouse farming,

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nursery management, research environments, and educational applications. Although the current system uses straightforward threshold-based control, it provides a foundation for future intelligent greenhouse systems. Incorporating predictive analytics, adaptive thresholds, machine learning, additional sensors, mobile applications, and large-scale field validation can further improve the intelligence, reliability, and scalability of the proposed platform.

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