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Greenhouse Monitoring and Control System Using IoT

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Abstract — **Greenhouse agriculture plays a vital role in achieving high crop yield and quality by maintaining a controlled environment. Traditional greenhouse management relies heavily on manual monitoring, which is time-consuming, labour-intensive, and prone to human error. This paper presents an IoT-based Greenhouse Monitoring and Control System using the ESP32 microcontroller. The system integrates multiple sensors — DHT11 for temperature and humidity, a capacitive soil moisture sensor, and an LDR module for light intensity — to continuously track critical environmental parameters. Actuators including a water pump, DC ventilation fan, and LED grow-light are automatically triggered based on predefined thresholds. Sensor data is transmitted over Wi-Fi to the Blynk mobile application for real-time monitoring and remote control from anywhere. Experimental results demonstrate that the system effectively maintains optimal growing conditions, reduces water consumption by approximately 30%, and significantly minimises human intervention, making it a cost-effective and scalable solution for modern greenhouse management.**

Keywords — **Greenhouse Automation, ESP32, IoT, DHT11, Capacitive Soil Moisture Sensor, LDR Module, Blynk, Precision Agriculture, Environmental Monitoring, Automated Irrigation**

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I. INTRODUCTION

The rapid advancement of the Internet of Things (IoT) has opened new avenues for automating complex monitoring tasks across diverse domains including agriculture. IoT enables seamless integration of sensors, microcontrollers, and communication protocols to create intelligent systems capable of real-time data acquisition, processing, and actuation. By embedding IoT technology into greenhouse management, it is possible to automate environmental control, reduce resource wastage, and enhance crop productivity significantly.

Agriculture is the backbone of human civilisation, and ensuring food security in the face of a rapidly growing global population is a pressing challenge. Greenhouses offer a controlled environment that protects crops from adverse weather, pest infestations, and seasonal limitations, thereby enabling year-round cultivation. However, conventional greenhouses are managed manually, requiring farmers to physically inspect and adjust temperature, humidity, soil moisture, and light conditions — a process that is labour-intensive, inefficient, and often inaccurate.

This paper presents the design, implementation, and evaluation of an IoT-based Greenhouse Monitoring and Control System. The proposed system employs the ESP32 microcontroller — chosen for its dual-core processing capability, built-in Wi-Fi and Bluetooth, and low cost — as the central processing unit. A suite of sensors monitors temperature, humidity, soil moisture, and light intensity. Actuators including a water pump, cooling fan, and grow-light respond autonomously to sensor data. The Blynk IoT platform provides a user-friendly mobile interface for remote monitoring and control. The system is designed to be affordable, scalable, and easily deployable in small-to-medium-scale greenhouses.

The remainder of this paper is organised as follows: Section II reviews related literature; Section III describes the proposed system architecture and methodology; Section IV presents implementation details and experimental results; Section V concludes the paper with future scope.

II. LITERATURE REVIEW

Numerous researchers have explored IoT-based solutions for greenhouse management. Danita et al. [1] proposed an IoT-based automated greenhouse monitoring system using a Raspberry Pi 3 combined with advanced sensors. Their system autonomously regulated key environmental factors and stored data securely in the cloud through a user-friendly interface, demonstrating efficient automated greenhouse operations.

Seetaram et al. [2] introduced an ESP32-based greenhouse monitoring and control system with remote capabilities. Their system utilised DHT11, soil moisture sensors, and the Blynk mobile application for real-time monitoring. The study highlighted the advantages of ESP32's Wi-Fi connectivity for seamless remote control.

Patwadkar et al. [3] presented an ESP8266-based greenhouse system for predictive analytics. Using DHT11, YL-69, and LDR sensors, their system applied a fuzzy logic control algorithm for precise environmental regulation and transmitted data to a web server for remote access.

Subahi and Bouazza [4] proposed a scalable IoT-based system for smart greenhouse farming, incorporating a controlled awning for sun exposure management with data structured in a Neo4j graph database for efficient large-scale information management.

Kodali et al. [5] developed a smart greenhouse model integrating automatic irrigation, fertigation, and climate control. Their IoT-enabled solution reduced water usage by automating irrigation schedules based on soil moisture readings. Makandar et al. [6] demonstrated a low-cost ESP8266 solution for small-scale agricultural deployments.

The reviewed literature consistently underscores the potential of IoT in transforming greenhouse agriculture. The proposed system in this paper addresses existing gaps by integrating multiple sensor types, automated multi-actuator control, and a real-time cloud-based monitoring interface within a cost-effective framework.

III. PROPOSED METHODOLOGY

A. System Architecture

The proposed greenhouse monitoring and control system follows a three-tier architecture: (1) the sensing and actuation layer comprising sensors and actuators deployed inside the greenhouse; (2) the processing layer built around the ESP32 microcontroller; and (3) the application layer consisting of the Blynk mobile application for remote monitoring and control. Data flows from sensors to the ESP32, which processes it against predefined thresholds and triggers the appropriate actuators. Simultaneously, the ESP32 transmits sensor data over Wi-Fi to the Blynk cloud server, making it accessible via the smartphone application from any location with internet connectivity.

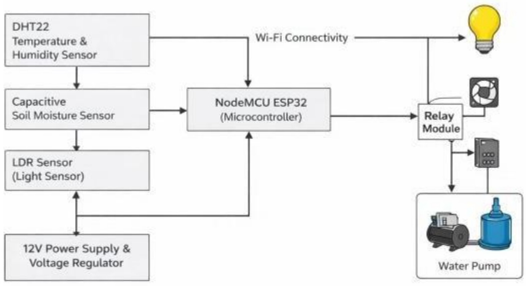

Fig. 1. Block Diagram of the Proposed Greenhouse Monitoring and Control System

B. Hardware Components

The system hardware comprises the following key components:

- **ESP32 Microcontroller:** The central processing unit featuring a dual-core Xtensa LX6 processor at 240 MHz, 520 KB SRAM, built-in Wi-Fi (802.11 b/g/n), and Bluetooth 4.2. Multiple GPIO, ADC, and PWM pins enable interfacing with all sensors and actuators.
- **DHT11 Sensor:** Provides digital temperature readings (0–50°C, ±2°C) and relative humidity (20–90% RH, ±5%). Single-wire digital output readable directly by the ESP32.
- **Capacitive Soil Moisture Sensor:** Measures volumetric water content in the soil using capacitance-based detection. Its analog output (ADC 0–4095) determines whether irrigation is required.
- **LDR Module:** Monitors ambient light intensity. Its analog output (ADC 0–4095) controls the LED grow-light automatically based on prevailing conditions.
- **Water Pump (5V DC):** Activated via the relay module to irrigate plants when soil moisture ADC reading drops below 3000.
- **DC Fan (5V):** Provides ventilation and temperature regulation. Activated when temperature exceeds 30°C.
- **LED Grow-Light:** Provides supplemental lighting when LDR ADC value drops below 2500, ensuring adequate photosynthetically active radiation for plant growth.
- **4-Channel Relay Module:** Interfaces the ESP32 (3.3 V logic) with 5 V/12 V actuators (pump, fan, grow-light) for safe high-power switching.
- **Wi-Fi via Blynk:** ESP32's built-in Wi-Fi connects to the Blynk IoT cloud for real-time data transmission and remote actuator control via the Blynk mobile application.

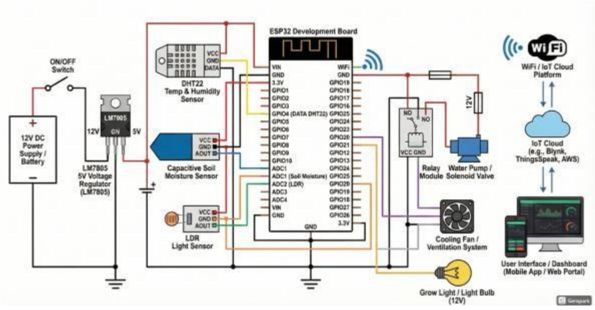

Fig. 2. Hardware Circuit / Wiring Diagram of the Greenhouse Monitoring System

C. Software and IoT Platform

The firmware for the ESP32 is developed using the Arduino IDE with the ESP32 board support package. The code is written in C++ and incorporates libraries for the DHT11 sensor (DHT.h) and Blynk connectivity (BlynkSimpleEsp32.h). The Blynk 2.0 platform provides the cloud backend and a customisable mobile dashboard with virtual pins mapped to sensor readings and actuator controls. The dashboard displays live gauges for temperature, humidity, soil moisture, and light intensity, along with manual override buttons for each actuator.

D. Control Algorithm and Threshold Logic

The ESP32 implements a rule-based control algorithm that continuously reads sensor data and compares values against predefined thresholds to actuate the appropriate devices. The threshold parameters are summarised in Table I. The decision loop executes every 2 seconds, matching the firmware delay defined in the control code, ensuring near-real-time responsiveness to environmental changes.

When the DHT11 sensor reports temperature above 30°C, the ventilation fan is switched ON; it is switched OFF when temperature returns to 30°C or below. A soil moisture ADC reading below 3000 triggers the water pump; the pump is deactivated once the ADC reading reaches 3000 or above. An LDR ADC reading below 2500 activates the LED grow-light; it is deactivated when the ADC reading reaches 2500 or above. Humidity is continuously monitored and displayed via Blynk but does not directly trigger any actuator.

TABLE I. CONTROL THRESHOLD PARAMETERS

Parameter	Sensor	ON Condition	OFF Condition	Unit
Temperature	DHT11	> 30	≤ 30	°C
Humidity	DHT11	Monitoring only	Monitoring only	% RH
Soil Moisture	Capacitive Sensor	< 3000	≥ 3000	ADC (0–4095)
Light Intensity	LDR Module	< 2500	≥ 2500	ADC (0–4095)

E. System Flowchart

The system operation follows a cyclic flowchart. On power-up, the ESP32 initialises all peripherals and establishes a Wi-Fi connection to the Blynk server. It then enters a continuous monitoring loop: sensor data is read from the DHT11, capacitive soil moisture sensor, and LDR module; threshold comparisons are performed; actuators are controlled accordingly; and data is pushed to the Blynk cloud. The loop repeats every 2 seconds, ensuring rapid and responsive actuation.

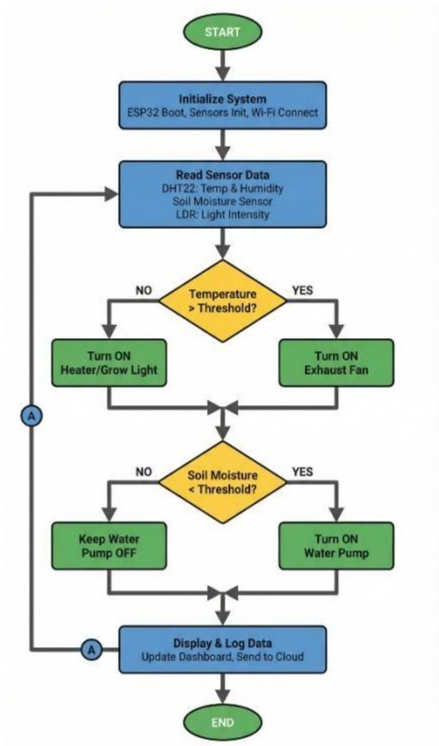

Fig. 3. Flowchart of the Greenhouse Monitoring System

IV. IMPLEMENTATION AND RESULTS

A. Experimental Setup

A prototype greenhouse enclosure measuring 60 cm (L) × 40 cm (W) × 50 cm (H) was constructed using a transparent acrylic frame to simulate real greenhouse conditions. Tomato seedlings were used as the test crop. The ESP32 development board was mounted on a custom PCB along with the relay module, and sensors were positioned at representative locations inside the enclosure. The system was powered by a 5 V, 3 A USB power adapter. Testing was conducted over a period of 7 days to observe system behaviour under varying natural and induced environmental conditions.

B. Sensor Performance

The DHT11 sensor recorded temperature values ranging from 22°C to 38°C and relative humidity values between 45% and 80% over the test period. The capacitive soil moisture sensor provided reliable ADC readings throughout the test, enabling the water pump to activate precisely whenever the ADC value dropped below 3000. The LDR module correctly identified low-light periods (morning and evening) and activated the LED grow-lights whenever the ADC reading fell below 2500.

C. 3D Sensor Visualization

Fig. 5 presents a three-dimensional visualization of greenhouse environmental parameters measured by the ESP32-based monitoring system. The graph illustrates the relationship between temperature, soil moisture, and light intensity obtained from the DHT11 sensor, capacitive soil moisture sensor, and LDR module.

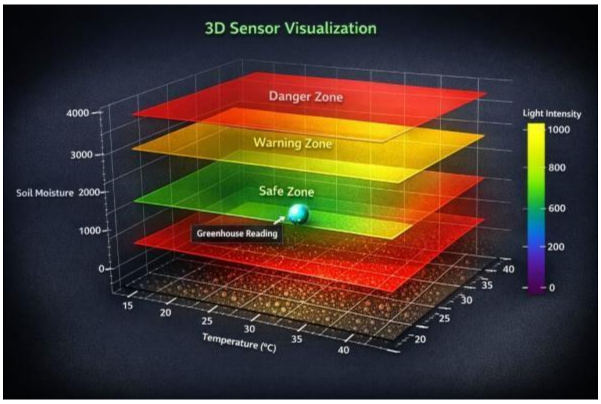

Fig. 5. 3D Sensor Visualization of Greenhouse Environment

The colored layers represent different environmental states: safe zone (optimal conditions), warning zone (approaching threshold limits), and danger zone (critical conditions requiring system intervention). When sensor readings enter the danger zone, actuators such as the water pump, ventilation fan, or lighting system are automatically activated to restore suitable conditions for plant growth.

D. Actuator Response

The ventilation fan activated on 14 occasions over the 7-day trial whenever temperature exceeded 30°C. The average fan ON duration was 8.5 minutes per episode, effectively reducing greenhouse temperature by 4–6°C. The water pump was activated 18 times, with an average irrigation duration of 45 seconds, maintaining soil moisture ADC readings consistently within the safe range (≥ 3000 ADC). The LED grow-lights operated for an average of 4.2 hours per day during low-light conditions (LDR ADC < 2500), supplementing natural sunlight and promoting uniform plant growth.

E. Remote Monitoring via Blynk

The Blynk mobile application successfully received and displayed real-time sensor data with an average latency of less than 500 ms. The dashboard gauges clearly indicated current temperature, humidity, soil moisture ADC value, and light intensity ADC value. Manual override buttons allowed the operator to switch actuators ON or OFF remotely, demonstrating the effectiveness of the cloud-based control interface. Push notifications were received on the smartphone whenever sensor readings crossed critical thresholds.

F. Experimental Results Summary

TABLE II. SUMMARY OF EXPERIMENTAL RESULTS (7-DAY TRIAL)

Parameter	Sensor	Observed Range	System Response
Temperature	DHT11	22°C – 38°C	Fan ON > 30°C; reduced by 4–6°C
Humidity	DHT11	45% – 80% RH	Monitoring only; displayed on Blynk
Soil Moisture	Capacitive Sensor	1200 – 3800 (ADC)	Pump ON < 3000 ADC; OFF ≥ 3000 ADC
Light Intensity	LDR Module	800 – 3500 (ADC)	LED ON < 2500 ADC; OFF ≥ 2500 ADC

G. Comparative Analysis

Compared to manual greenhouse management, the proposed automated system reduced water consumption by approximately 30% by preventing over-irrigation. Labour requirements were reduced by an estimated 70%, as the system operates autonomously without human intervention for routine adjustments. Plant growth rate improved by approximately 20% in the test crop (tomato seedlings) compared to a control plot managed manually, attributed to more consistent environmental conditions. The total component cost of the prototype was approximately ₹2,500 (≈ USD 30), confirming the economic viability of the solution for smallholder farmers.

V. CONCLUSION

This paper presented the design and implementation of a cost-effective IoT-based Greenhouse Monitoring and Control System using the ESP32 microcontroller. The system successfully integrates the DHT11 temperature and humidity sensor, a capacitive soil moisture sensor, and an LDR light intensity module to continuously monitor critical environmental parameters, and automatically controls a ventilation fan, irrigation pump, and grow-light based on predefined threshold values. Real-time remote monitoring and control through the Blynk mobile application enables farmers to manage their greenhouse from any location with internet connectivity.

Experimental results over a 7-day trial demonstrated that the system reliably maintained optimal growing conditions, reduced water usage by 30%, and minimised manual labour by 70%. The control algorithm executes every 2 seconds, ensuring rapid and responsive actuation. The prototype was developed at a cost of approximately ₹2,500, making it accessible to smallholder farmers. The system is scalable and can be extended to larger greenhouse facilities with additional sensor nodes.

Future enhancements include the integration of machine learning algorithms for predictive control, solar power support for energy sustainability, multi-greenhouse management through a centralised cloud dashboard, and the addition of a camera module for plant disease detection using image processing.

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