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Smart Greenhouse Monitoring & Control

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ABSTRACT: This paper presents a Smart Greenhouse Monitoring & Control System designed to automate real-time environmental monitoring using Internet of Things (IoT) technology. The system integrates seven sensors to continuously measure temperature, humidity, soil moisture, gas concentration (CO and air quality), light intensity, voltage, and current inside the greenhouse. An ESP32 microcontroller collects sensor data and transmits it using the LoRa RA-02 communication module (433 MHz), enabling long-distance wireless communication up to 2 km with minimal power consumption. The received data is forwarded to a web server via Wi-Fi, stored in a MySQL database, and displayed on a real-time responsive web dashboard. Automatic fan control operates in three modes: Manual ON, Manual OFF, and Auto (temperature-based hysteresis). Alert notifications are delivered via Telegram Bot and Email when sensor readings exceed configured thresholds. The entire system is powered by a 20W solar panel with 12V battery backup and PWM charge controller, making it energy-efficient and suitable for remote agricultural areas.

KEYWORDS: IoT, ESP32, LoRa RA-02, DHT11, Soil Moisture Sensor, MQ135, MQ7, ACS712, Solar Power, MySQL, PHP, Web Dashboard, Smart Agriculture, Fan Control, Telegram Bot.

I. INTRODUCTION

Greenhouse cultivation plays an important role in modern agriculture by providing a controlled environment for plant growth. However, traditional greenhouse management often depends on manual observation of environmental parameters such as temperature, humidity, soil moisture, and light intensity. Manual methods are time-consuming, less accurate, and may not provide immediate response to sudden environmental changes, which can negatively affect crop health and productivity.

The rapid growth of the Internet of Things (IoT) has enabled the development of automated agricultural monitoring systems that improve efficiency and decision-making. Smart greenhouse systems use sensors, wireless communication, and web-based interfaces to continuously monitor crop conditions and support timely control actions. Among available wireless technologies, LoRa has gained attention due to its long-range capability and low power consumption, making it suitable for agricultural applications [1].

This paper proposes a Smart Greenhouse Monitoring & Control System using ESP32, LoRa communication, solar power, and a web dashboard. The system monitors key environmental conditions, stores data in a database, generates alerts, and controls a fan automatically when required. The proposed design aims to provide a practical, low-cost, and energy-efficient solution for greenhouse monitoring in both rural and semi-urban areas.

II. LITERATURE REVIEW

Recent studies in smart agriculture have focused on IoT-based systems for greenhouse monitoring and control. Many existing solutions use microcontrollers such as Arduino, ESP8266, and ESP32 combined with sensors for temperature, humidity, soil moisture, and light intensity. These systems typically rely on Wi-Fi, GSM, or cloud platforms for data transmission and visualization [2][3].

Researchers have demonstrated that automated greenhouse monitoring systems reduce labor requirements and improve crop productivity by maintaining optimal environmental conditions. Web dashboards and mobile applications are

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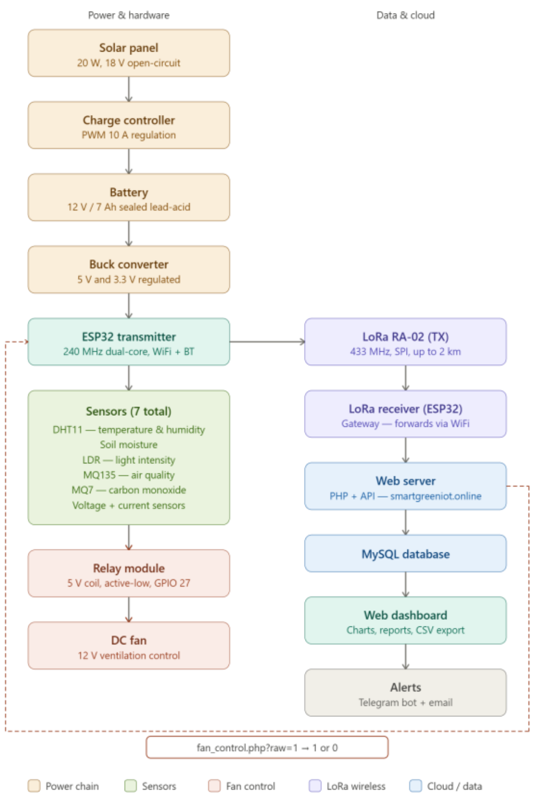
commonly used to provide real-time access to sensor data and support decision-making [4][5]. Some systems also integrate automatic irrigation and ventilation control to enhance greenhouse efficiency.

LoRa-based agricultural systems have become increasingly important because of their ability to support long-range communication with low power usage, especially useful in remote farming areas where direct Wi-Fi coverage may not be available [6]. In addition, solar-powered IoT systems have been proposed to ensure uninterrupted operation and promote sustainable agricultural practices.

Although many existing systems offer valuable features, some are limited by short communication range, dependence on stable internet connectivity, or higher operating cost. The system proposed in this paper addresses these challenges by combining ESP32, LoRa, solar power, web-based data monitoring, alert generation, and fan automation in a unified greenhouse solution.

III. SYSTEM METHODOLOGY

The proposed system is divided into sensing, processing, communication, storage, monitoring, and control stages. Each stage is designed to operate reliably and efficiently in a greenhouse environment.



A. Proposed System Architecture

The proposed solution collects real-time environmental data such as temperature, humidity, soil moisture, light intensity, and gas levels using sensors connected to an ESP32 microcontroller. The system transmits this data using LoRa communication to a receiver, which forwards it to a web server for storage and display. A relay module automatically controls a fan based on temperature conditions. Alerts are delivered through email or Telegram, making the system efficient, automated, and suitable for modern agriculture.

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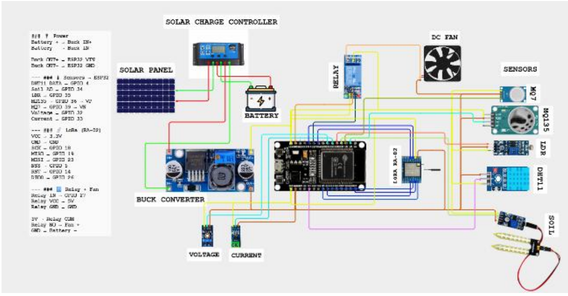


B. Sensor Data Acquisition

The greenhouse unit consists of multiple sensors connected to the ESP32 microcontroller. The DHT11 sensor measures temperature and humidity; the soil moisture sensor measures soil water level; the LDR measures light intensity; MQ135 monitors air quality; MQ7 detects gas (CO) concentration; and voltage and current sensors monitor the solar power system continuously.

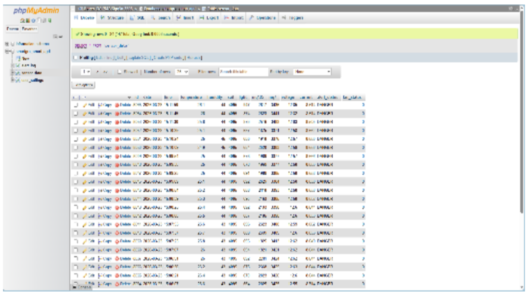
C. Processing Unit

The ESP32 acts as the main controller. It reads all sensor values, applies noise-reduction averaging techniques, and prepares the data for wireless transmission. It also supports local control of the relay and fan depending on system-defined conditions and incoming commands from the web dashboard or Telegram bot.

D. LoRa Communication

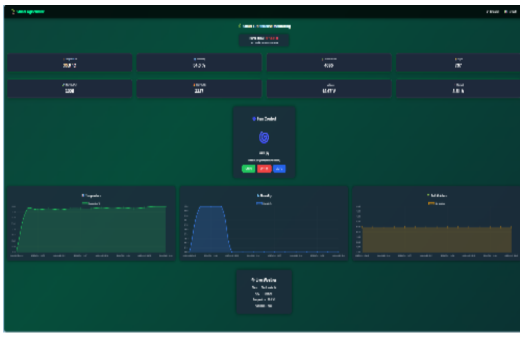
The LoRa RA-02 module operating at 433 MHz is used to transmit sensor readings from the greenhouse transmitter node to the receiver node. This communication method is selected because it supports long-distance transmission (up to 2 km) while consuming significantly less power than conventional wireless technologies such as Wi-Fi or GSM.

E. Server and Database



At the receiver side, the ESP32 forwards data to a web server through Wi-Fi. The backend is developed using PHP, and the collected sensor values are stored in a MySQL database. This architecture supports both real-time monitoring and historical record maintenance with date-range filtering and CSV data export.

F. Web Dashboard and Alerts



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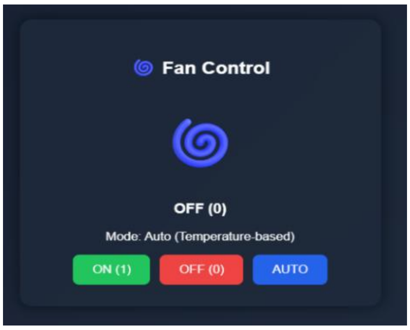
The stored sensor data is displayed through a responsive web dashboard developed using HTML, CSS, JavaScript, and Chart.js. The dashboard shows live sensor readings, graphical trends, and device online/offline status with auto-refresh at configurable intervals. Alerts are generated via Telegram Bot and Email when environmental values exceed predefined safety thresholds. A 10-minute cooldown prevents duplicate alert messages.
(website link : Smart Agriculture Dashboard)

G. Automatic Fan Control



A relay module connected to a DC fan is used for ventilation control. The system supports three fan control modes: Manual ON (value 1), Manual OFF (value 0), and Auto mode (temperature-based hysteresis). In Auto mode, the relay activates the fan when the measured temperature exceeds a threshold, and deactivates it when the temperature drops below the lower hysteresis limit. The ESP32 polls fan_control.php every 5 seconds.

H. Solar Power Supply

The entire system is powered by a 20W solar panel with a 12V battery backup and PWM charge controller. A buck converter provides a stable 5V operating voltage to the ESP32 and associated components. This design enables continuous off-grid operation, making the system particularly suitable for remote agricultural areas in Tamil Nadu and across India.

IV. SYSTEM WORKFLOW

The step-by-step operational workflow of the proposed system is as follows:
Step 1: The solar panel generates power and charges the battery through the PWM charge controller.
Step 2: The buck converter reduces the battery voltage to a stable 5V level for the ESP32 and sensors.
Step 3: Environmental sensors (DHT11, soil moisture, LDR, MQ135, MQ7, voltage, and current) collect greenhouse data.
Step 4: The ESP32 microcontroller reads, averages, and processes the sensor values.
Step 5: The processed data is transmitted through the LoRa RA-02 module to the receiver ESP32.
Step 6: The receiver ESP32 sends the data to the web server using Wi-Fi.
Step 7: The PHP backend stores the received data in the MySQL database.
Step 8: The web dashboard displays real-time sensor readings and graphical trends.
Step 9: If the temperature exceeds the preset threshold, the ESP32 activates the relay module.
Step 10: The relay turns ON the DC fan to reduce the temperature inside the greenhouse.
Step 11: If abnormal conditions are detected, alerts are sent through email or Telegram Bot.

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V. RESULTS AND DISCUSSION

The developed Smart Greenhouse Monitoring System successfully acquires and transmits environmental and power-related data in real time. All measured parameters—temperature, humidity, soil moisture, light intensity, gas values, voltage, and current—are displayed on the web dashboard and stored in the database, confirming the suitability of the proposed architecture for greenhouse monitoring applications.

The implementation of LoRa communication significantly improves the operational range of the system. Unlike Wi-Fi-based sensing nodes that require proximity to an internet access point, the LoRa-based greenhouse node can be placed up to 2 km from the receiver. This makes the design more practical for rural and large-field applications. Since greenhouse sensing mainly involves periodic transmission of low-bandwidth data, the lower data rate of LoRa does not create a significant limitation.

The solar-powered design further increases the effectiveness of the system by enabling independent field operation. The battery backup supports continuity during low sunlight periods, while the buck converter ensures safe voltage regulation. The relay-controlled fan demonstrates the automation capability of the system by responding to environmental changes without constant user intervention.

The total estimated hardware cost of approximately ₹5,800 makes this system significantly more affordable than commercial greenhouse monitoring solutions, while delivering comparable functionality through open-source hardware and software.

TABLE I. Sensor Parameters and Measured Ranges

Sensor	Parameter	Range / Unit
DHT11	Temperature / Humidity	0–50°C / 20–90% RH
Soil Moisture Sensor	Soil Water Content	0–100%
LDR	Light Intensity	0–1023 (ADC)
MQ135	Air Quality (CO_2, NH_3)	PPM
MQ7	Carbon Monoxide (CO)	PPM
Voltage Sensor	Solar/Battery Voltage	0–25V
ACS712	Current	0–5A

Despite these advantages, some challenges remain. Sensor readings may vary depending on calibration quality and environmental interference. LoRa is well suited for periodic sensor data transfer but is not appropriate for high-volume data applications. Similarly, solar system performance depends on sufficient sunlight and proper battery management. The overall system provides a reliable, cost-effective, and scalable greenhouse monitoring solution.

VI. CONCLUSION

The Smart Greenhouse Monitoring & Control System has been successfully designed, developed, and tested. The system integrates seven environmental sensors, LoRa long-range wireless communication, solar power, and a comprehensive web-based platform to provide complete real-time greenhouse monitoring and automated control.

All project objectives have been achieved. The ESP32-based transmitter reliably collects sensor data using noise-reduction averaging techniques. The LoRa RA-02 module successfully transmits data over distances up to 2 km with minimal power consumption at 433 MHz. The three-mode fan control system operates reliably, and the web dashboard provides a professional, responsive interface with live sensor readings, graphical trends, historical data reports, CSV export, and live weather integration.

The project contributes meaningfully to SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 9 (Industry, Innovation and Infrastructure), and SDG 13 (Climate Action). Future enhancements will include a mobile application for push notifications, AI/ML-based crop disease prediction, automated drip irrigation control, and support for multiple greenhouse units from a single dashboard.

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