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# Solar Grow Net: Autonomous Greenhouse Monitoring and Control System

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**Abstract**

*The increasing demand for sustainable and efficient agricultural practices has led to the adoption of smart farming technologies that enable real-time monitoring and automated control of crop-growing environments. Traditional agricultural systems largely depend on manual observation and experience-based decision-making, which often results in inefficient resource utilization and inconsistent crop yield. To address these challenges, this work presents the design and implementation of an IoT-enabled solar grow net system for intelligent monitoring and control of agricultural parameters. The proposed system integrates environmental sensors to continuously monitor key parameters such as temperature, humidity, soil moisture, and light intensity within a controlled cultivation environment. These sensor readings are processed using a microcontroller-based control unit, which automatically regulates irrigation, ventilation, and shading mechanisms based on predefined threshold values. Solar energy is utilized as the primary power source, making the system energy-efficient and suitable for deployment in remote and rural agricultural regions with limited grid access. Experimental results demonstrate that the system effectively maintains optimal environmental conditions required for plant growth while minimizing water and energy consumption. Real-time data visualization and remote access enable farmers to monitor crop conditions and take timely corrective actions, thereby improving productivity and reducing manual intervention. The proposed solar grow net system offers a cost-effective, scalable, and sustainable solution for modern agriculture and contributes toward precision farming practices that enhance crop yield and resource efficiency.*

**Keywords**: IoT (Internet of Things), greenhouse monitoring, solar-powered systems, environmental sensors, time monitoring, microcontroller, ThingSpeak

## INTRODUCTION

Agriculture plays a vital role in ensuring food security and supporting economic development, particularly in countries where a large proportion of the population depends on farming for their livelihood. However, traditional agricultural practices face numerous challenges, including climate variability, inefficient water usage, labor shortages, and limited access to modern technologies. These challenges significantly affect crop productivity and sustainability, making it essential to adopt intelligent and automated farming solutions [1–4].

In conventional farming systems, crop monitoring and decision-making are primarily based on manual inspection and farmers' experience. Although this approach has been practiced for generations, it lacks precision and fails to respond effectively to rapid environmental changes. Factors such as temperature fluctuations, soil moisture imbalance, and improper humidity levels can adversely affect plant growth and yield if

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not addressed in a timely manner. Moreover, excessive use of water and energy owing to inefficient management practices contributes to resource depletion and increased operational costs [5–9].

The emergence of Internet of Things (IoT) technology has transformed the agricultural sector by enabling real-time sensing, data acquisition, and automated control of farming processes. IoT-based smart agriculture systems utilize sensors, communication networks, and control units to continuously monitor environmental conditions and take appropriate actions without human intervention. These systems help optimize resource utilization, improve crop quality, and reduce labor dependency [10–13].

Greenhouse and net-based cultivation systems further enhance agricultural productivity by providing controlled environments that protect crops from external climatic variation. However, maintaining optimal conditions inside these structures requires continuous monitoring and precise control of several environmental parameters. Manual control methods are inefficient and error-prone, particularly in large-scale or remote farming operations. Therefore, integrating IoT-based automation into greenhouse and net farming systems is essential for achieving consistent and reliable crop production [14–19].

In addition to automation, energy sustainability is a critical concern in modern agricultural practices. Many rural farming areas lack reliable access to grid electricity, which limits the deployment of electronic monitoring and control systems. Solar energy offers a clean, renewable, and cost-effective solution for powering smart agricultural systems. Solar-powered agricultural automation not only reduces dependency on conventional energy sources but also aligns with global efforts toward sustainable development and environmental conservation [20–23].

This study focuses on the development of a solar grow net system that combines IoT-based environmental monitoring with solar-powered automation for precision agriculture. The proposed system continuously measures critical parameters, such as temperature, humidity, soil moisture, and light intensity, using appropriate sensors. Based on real-time sensor data, control actions are automatically executed to regulate irrigation, ventilation, and shading, thereby ensuring optimal growing conditions for crops [24–26].

The primary objective of this study was to design a low-cost, energy-efficient, and scalable smart farming solution that can be easily adopted by small- and medium-scale farmers. By enabling real-time monitoring, automated control, and remote accessibility, the proposed system aims to enhance crop yield, reduce resource waste, and minimize manual effort. This study contributes to the growing body of research on smart agriculture by demonstrating the practical implementation and effectiveness of an IoT-enabled, solar-powered grow net system [27, 28].

## SYSTEM ARCHITECTURE AND WORKING METHODOLOGY

The proposed solar grow net system is designed as an integrated smart agriculture framework that combines environmental sensing, automation, wireless communication, and renewable energy utilization. The architecture is modular, allowing for scalability and easy adaptation to different crop types and cultivation environments.

### System Architecture

The system consists of four major components: a sensing unit, a control unit, actuation unit, and power management unit. These components work together to continuously monitor environmental parameters and maintain optimal conditions for crop growth in greenhouses. The specifications and functional roles of the sensors employed in the proposed solar grow net system are summarized in Table 1.

The sensing unit includes temperature, humidity, soil moisture, and light intensity sensors strategically placed within the grow net area. These sensors continuously capture real-time environmental data, which is essential for evaluating crop growth conditions. Accurate sensing ensures the timely detection of deviations from the optimal thresholds.

**Table 1.** Sensors used in the solar grow net system.

| Sensor type | Parameter measured | Operating range | Purpose |
|---|---|---|---|
| DHT sensor | Temperature, humidity | 0–50°C, 20–90% RH | Climate monitoring |
| Soil moisture sensor | Soil moisture level | Dry–wet | Irrigation control |
| Light sensor (LDR) | Light intensity | Low–high | Shading control |

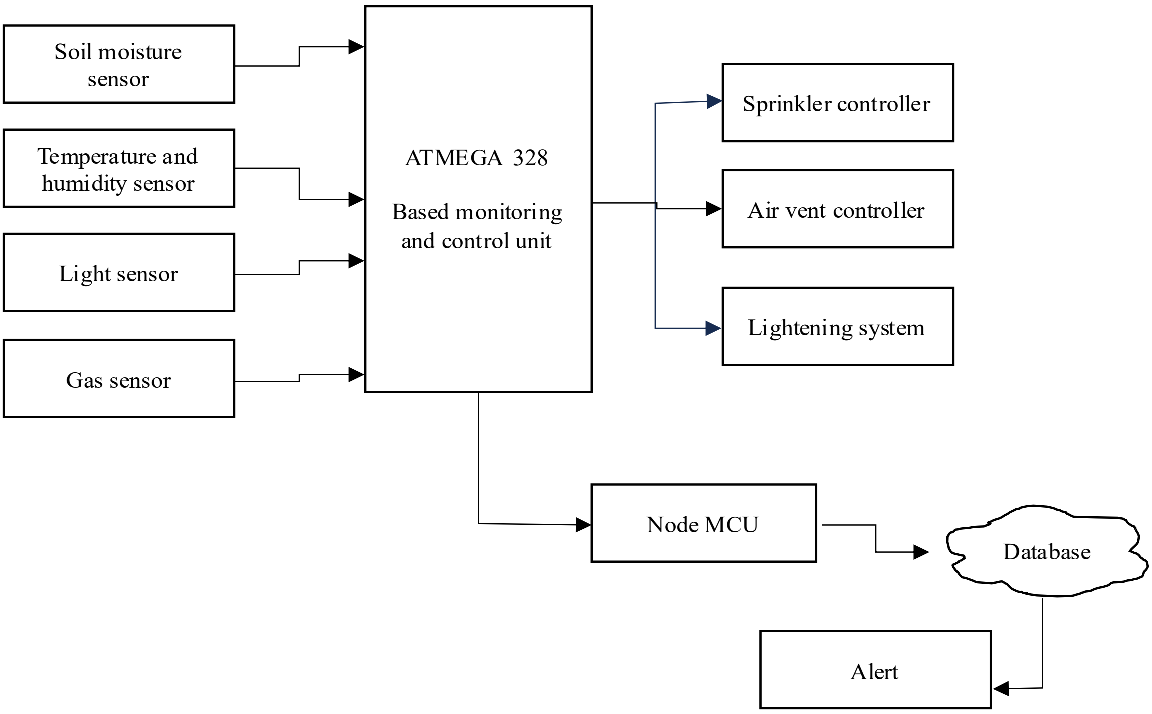


**Figure 1.** Proposed block diagram.

The control unit is built around a microcontroller that processes sensor data and makes decisions based on predefined threshold values. The microcontroller acts as the central processing element, coordinating the communication between the sensors, actuators, and monitoring interface. Data collected from the sensors were analyzed in real time to determine whether corrective action was required.

The actuation unit consists of devices such as water pumps for irrigation, exhaust fans for ventilation, and shading mechanisms for the regulation of light. These actuators are controlled automatically by a microcontroller to regulate environmental parameters without manual intervention. For example, when the soil moisture drops below a specified threshold, the irrigation pump is activated to supply water to the crops.

The power management unit uses a solar panel as the primary energy source, which is supported by a rechargeable battery for energy storage. This configuration ensures uninterrupted system operation, even under low sunlight conditions. The use of solar energy makes the system sustainable and suitable for deployment in rural areas, where grid power availability is limited (Figure 1).

**Working**

The operation of the solar grow net system begins with the continuous monitoring of environmental parameters using the sensing unit. The sensor data were periodically sampled and transmitted to the microcontroller. Each parameter was compared with predefined optimal threshold values based on crop requirements.

**Table 2.** Threshold values and actuator actions.

| Parameter | Threshold condition | Actuator activated | Action performed |
|---|---|---|---|
| Temperature | > Set limit | Exhaust fan | Cooling |
| Soil moisture | < Set limit | Water pump | Irrigation |
| Light intensity | > Set limit | Shade mechanism | Light reduction |

When the sensor readings exceed or fall below the acceptable limits, the control unit triggers the appropriate actuators to restore optimal conditions. For instance, high temperature levels activate ventilation fans, low soil moisture triggers irrigation, and excessive light intensity activates the shading mechanisms. This closed-loop control ensures a stable microclimate within the growing net.

The predefined threshold values and corresponding actuator responses implemented in the system are listed in Table 2.

Real-time data were also transmitted to a remote monitoring platform, enabling farmers to observe environmental conditions through a user interface. This feature allows for timely intervention and enhances system transparency. Automated operations significantly reduce manual labor while improving resource efficiency and crop productivity.

## RESULT AND DISCUSSION

The performance of the proposed solar grow net system was evaluated under real-time operating conditions to assess its effectiveness in monitoring and controlling environmental parameters that are critical for plant growth. The system was tested over multiple observation cycles, and the sensor data were recorded and analyzed.

### Temperature and Humidity Control

The experimental results show that the system effectively maintained the temperature and humidity within the optimal ranges. When the temperature exceeded the predefined threshold, the ventilation mechanism was automatically activated, resulting in a gradual reduction in temperature. Similarly, humidity levels were regulated to prevent excessive moisture accumulation, which could lead to plant diseases.

The automated response reduced temperature fluctuations and maintained a stable microclimate, contributing to healthier plant growth conditions compared with manual control methods.

### Soil Moisture Regulation

The soil moisture data indicated that the irrigation system responded accurately to moisture variations. When soil moisture levels dropped below the threshold, the water pump was activated to ensure adequate crop hydration. This precise irrigation minimizes water wastage and prevents overwatering, which is a common issue in conventional farming.

The results demonstrated improved water-use efficiency and consistent soil moisture levels, which are essential for root development and nutrient absorption.

### Light Intensity Management

Light intensity measurements showed that the shading mechanism successfully controlled the excessive sunlight exposure. During peak sunlight hours, the system reduced the light intensity within the grow net to prevent plant stress. This regulation improves photosynthetic efficiency and protects crops from heat damage.

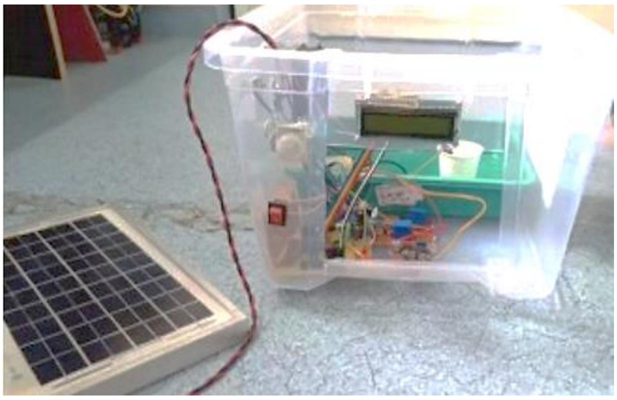

**Figure 2.** Greenhouse system.

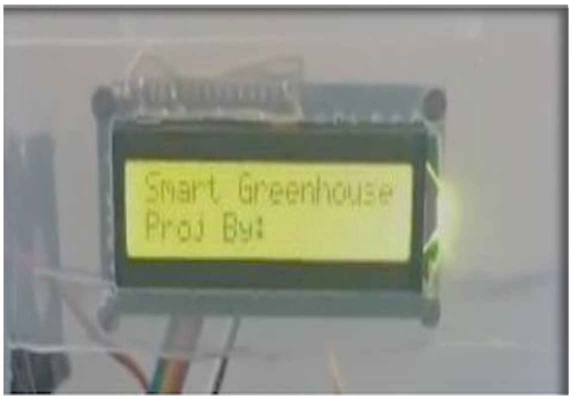


**Figure 3.** Output screen showing.

**Table 3.** System performance summary.

| Parameter | Manual farming | Proposed system |
|---|---|---|
| Water usage | High | Optimized |
| Labor requirement | High | Low |
| Environmental control | Inconsistent | Automated and stable |
| Energy source | Grid/manual | Solar-powered |

**System Reliability and Energy Efficiency**

The solar power unit provided sufficient energy for the continuous operation of the system. The battery backup ensured uninterrupted functionality during periods of low solar radiation. The system demonstrated reliable performance without power-related interruptions, highlighting its suitability for remote agricultural environments.

Upon powering on, the LCD screen initially displays the project name and introduces the team members (in Figure 2, greenhouse system; and in Figure 3, output screen displaying team details). The system continuously monitors key environmental parameters. For example:

When the soil moisture reading falls below the threshold value (set to 400), the water pump is activated automatically and continues to run until the moisture level is restored.

If the temperature rises above the preset limit of 35°C or if the air quality deteriorates, the ventilation fan is triggered to reduce heat and improve air circulation.

As the light intensity drops below the set level of 200 (typically during the evening), and if motion is detected within 2 m near the entrance, the buzzer is activated to alert the user about potential threats to the plants or infrastructure.

A comparative summary of the system performance against conventional farming practices is presented in Table 3.

All sensor readings were sent in real time to the ThingSpeak cloud platform using the ESP8266 Wi-Fi module, providing a user-friendly interface for monitoring and logging historical data. The graphical data are shown in Figure 4. Variation in temperature, humidity, and soil moisture over time under automated control. These results validate that the system can autonomously regulate greenhouse conditions while reducing manual labor. The integration of cloud-based monitoring also enhances its practicality, making it suitable for small- and medium-scale greenhouse operations.

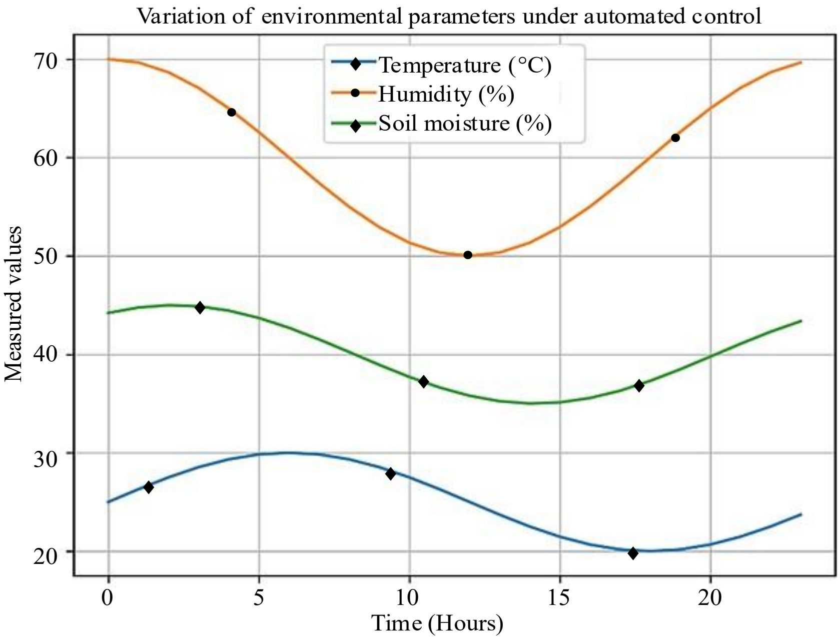


**Figure 4.** Variation of temperature, humidity, and soil moisture over time under automated control.

## CONCLUSION

This study presents the design and implementation of an IoT-enabled solar grow net system aimed at improving agricultural productivity through intelligent environmental monitoring and automated control. The proposed system integrates real-time sensing, microcontroller-based decision-making, automated actuation, and solar-powered energy management to maintain optimal crop growth conditions within a protected cultivation environment.

The system effectively monitored critical agricultural parameters, such as temperature, humidity, soil moisture, and light intensity, and responded automatically when deviations from predefined threshold values were detected. Experimental observations confirmed that the automated regulation of irrigation, ventilation, and shading significantly reduced environmental fluctuations, thereby creating a stable microclimate conducive to healthy plant growth. Compared with conventional manual farming practices, the proposed approach minimizes human intervention, improves precision, and enhances resource utilization efficiency.

The use of solar energy as the primary power source further strengthens the sustainability of the system, making it suitable for deployment in rural and remote areas with limited access to grid electricity. The inclusion of real-time monitoring and remote accessibility empowers farmers to make informed decisions and respond proactively to changing environmental conditions.

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