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IoT-Based Greenhouse Monitoring and Automation System Powered by Solar Energy

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Abstract: In modern agriculture, optimizing greenhouse conditions is crucial for enhancing crop yield and quality. This paper presents an IoT-based Greenhouse Monitoring and Automation System powered by solar energy to ensure efficient and sustainable farming. The system integrates various sensors to monitor temperature, humidity, soil moisture, and light intensity in real time. The collected data is transmitted to a cloud-based platform, allowing remote monitoring and control via a mobile or web application. Automation features include an intelligent irrigation system, ventilation control, and lighting adjustments based on predefined thresholds. The entire system is powered by solar energy, reducing dependence on conventional power sources and promoting eco-friendly farming practices.

Keywords: IoT-based greenhouse, Smart greenhouse, Greenhouse automation, Solar-powered greenhouse.

I. INTRODUCTION

Agriculture plays a vital role in ensuring food security, and greenhouse farming has become a popular method for enhancing crop productivity by providing controlled environmental conditions. However, manual monitoring and regulation of greenhouse parameters such as temperature, humidity, soil moisture, and light intensity can be inefficient and labor-intensive. To address these challenges, an (IoT)- Internet Of Things based greenhouse monitoring and automation system powered by solar energy is proposed.

Automation mechanisms are implemented to regulate irrigation, ventilation, and lighting, ensuring optimal growth conditions while minimizing human intervention. Additionally, the system operates on solar energy, making it an eco-friendly and sustainable solution that reduces reliance on conventional power sources.

By integrating (IoT) and renewable energy, this smart greenhouse system enhances productivity, conserves resources, and promotes sustainable agricultural practices. It provides farmers with a cost-effective and efficient approach to modern farming, ensuring higher yields and better resource management.

Greenhouse farming is an essential agricultural practice that ensures controlled environmental conditions for improved crop yield. However, maintaining an optimal greenhouse environment requires continuous monitoring of temperature, humidity, soil moisture, and light intensity. Traditional greenhouse management methods are labor-intensive and inefficient. With advancements in the Internet of Things (IoT) and renewable energy, solar-powered IoT-based greenhouse automation systems have emerged as sustainable solutions. This literature review presents research studies on IoT-based greenhouse monitoring and automation systems powered by solar energy, focusing on sensor technologies, wireless communication, solar power integration, and challenges.

Greenhouse farming is an essential agricultural practice that ensures controlled environmental conditions for improved crop yield. However, maintaining an optimal greenhouse environment requires continuous monitoring of temperature, humidity, soil moisture, and light intensity. Traditional greenhouse management methods are labor-intensive and inefficient. With advancements in the Internet of Things (IoT) and renewable energy, solar-powered IoT-based greenhouse automation systems have emerged as sustainable solutions. This literature review presents research studies on IoT-based greenhouse monitoring and automation systems powered by solar energy, focusing on sensor technologies, wireless communication, solar power integration, and challenges.

An automated greenhouse is a high-tech greenhouse that uses sensors and technology to control the environment for plant growth. It can monitor and adjust temperature, light, water, and other factors. A smart greenhouse system supports you in the central management and coordination of all processes to do with climate, light, irrigation, water, and energy management. The system automatically anticipates conditions and events that affect your cultivation, inside and outside your greenhouse.

An automated greenhouse project aims to create a self-regulating growing environment for plants by utilizing sensors to monitor key environmental parameters like temperature, humidity, light intensity, and soil moisture, and then automatically adjusting these conditions through actuators like fans, heaters, irrigation systems, and vents, ultimately optimizing plant growth and maximizing crop yields while minimizing manual labor and resource waste.

An automated greenhouse monitoring system powered by solar energy is a technological setup that utilizes solar power to run sensors and actuators within a greenhouse, allowing for continuous monitoring and automatic control of crucial environmental parameters like temperature, humidity, light levels, and soil moisture, optimizing plant growth and maximizing crop yields while minimizing manual intervention and promoting sustainability.

An automated greenhouse monitoring system is a technological setup that utilizes sensors to continuously measure key environmental parameters within a greenhouse, like temperature, humidity, light intensity, and soil moisture, and then automatically adjusts various control systems (heating, ventilation, irrigation) based on the collected data to optimize plant growth and maximize crop yield, minimizing manual intervention and ensuring consistent conditions for the plants throughout their lifecycle.

Greenhouse Technology is the technique of providing favorable environment condition to the plants. It is rather used to protect the plants from the adverse climatic conditions such as wind, cold, precipitation, excessive radiation, extreme temperature, insects and diseases.

The world is witnessing a significant shift towards sustainable and precision agriculture, driven by the need to increase crop yields, reduce water consumption, and minimize environmental impact. Greenhouses, in particular, offer a controlled environment for plant growth, enabling farmers to optimize crop production regardless of external weather conditions. However, traditional greenhouse management relies heavily on manual intervention, leading to inefficiencies and reduced productivity.

To address these challenges, this project proposes the development of an IoT-based greenhouse monitoring and automation system powered by solar energy. This innovative system integrates cutting-edge technologies, including sensors, wireless communication protocols, and machine learning algorithms, to create a smart and sustainable greenhouse ecosystem. By leveraging solar energy as the primary power source, the system reduces reliance on non-renewable energy sources, minimizing its carbon footprint and operating costs.

The proposed system enables real-time monitoring and automation of critical greenhouse parameters, such as temperature, humidity, light intensity, and soil moisture. This allows farmers to make data-driven decisions, optimize resource allocation, and respond promptly to any anomalies or issues. Ultimately, this IoT-based greenhouse monitoring and automation system has the potential to revolutionize the agriculture sector, promoting sustainable and precision farming practices that enhance crop yields, reduce waste, and contribute to a more food-secure future.

II. LITERATURE REVIEW

IoT-based Greenhouse Monitoring Systems

IoT for Smart Agriculture: Multiple studies have shown the significant benefits of IoT in monitoring greenhouse conditions. The integration of wireless sensors, actuators, and communication networks enables the automation of various processes such as irrigation, ventilation, and lighting. For example, Patil and Gajbhiye (2020)[1] discuss the implementation of IoT in agriculture, focusing on smart farming and how IoT can optimize resource use and improve yield quality.

Real-time Data and Control: In a study by Rani et al. (2019)[2], a smart IoT-based greenhouse system was designed to monitor key environmental parameters. The system was connected to a cloud server where the data was stored and analyzed, providing valuable insights for growers. The automatic control of the greenhouse environment through actuators (e.g., fans, irrigation) was based on sensor data, improving efficiency and reducing human intervention.

Solar-Powered IoT Greenhouses: A study by Kumar et al. (2020)[3] explored the integration of solar power with IoT-based greenhouse systems. They developed a solar-powered system that could autonomously manage irrigation, lighting, and climate control using energy collected from solar panels. This solution significantly reduced the operational cost of the greenhouse while promoting sustainable farming.

Solar Energy Efficiency and Cost-Effectiveness: In another study, Malik et al. (2018)[4] discussed the use of photovoltaic systems in IoT-based greenhouses. The authors highlighted the efficiency of solar panels in providing the necessary energy for the sensors and actuators in the greenhouse. Furthermore, they emphasized the economic benefits, including reduced energy bills and increased yield, due to optimal climate and water management.

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Energy Management and Storage: One significant challenge is ensuring a stable energy supply, as solar energy is intermittent. To address this, energy storage solutions like batteries are integrated into solar-powered systems. However, optimizing energy consumption and storage remains an active research area.[5]

Scalability and Maintenance: The scalability of IoT-based systems is another challenge. As these systems grow in size, managing the sensors and ensuring reliable communication becomes more complex. Additionally, maintaining solar power systems and ensuring their efficiency over long periods are critical aspects that need addressing.[6]

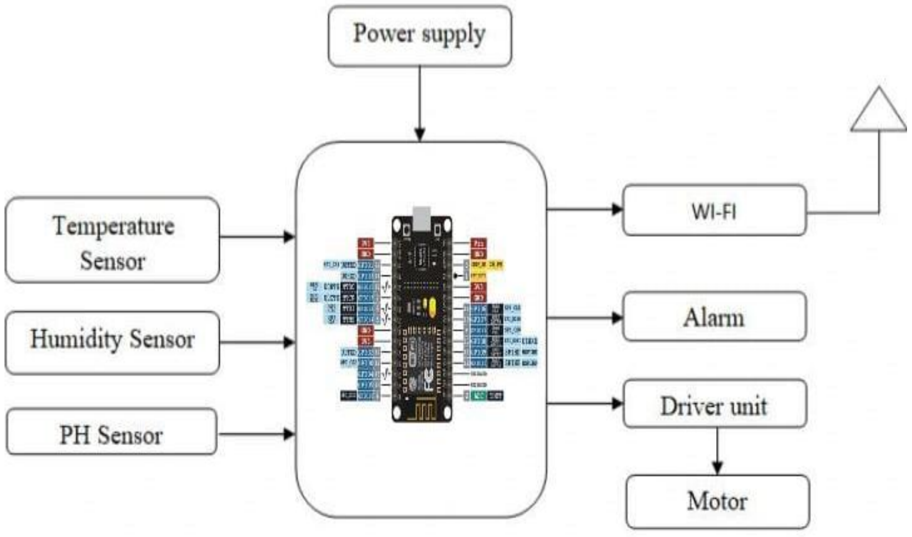
Smart Irrigation Systems: A study by Al-Jumaily et al. (2020) examined a smart irrigation system powered by solar energy and IoT. The system used soil moisture sensors to determine the optimal amount of water needed for crops, thereby reducing water wastage.[7]

Environmental Sustainability: The research by Ghosh et al. (2021) discussed the role of IoT-based greenhouses in reducing resource consumption (water, energy) and ensuring environmental sustainability. They proposed a hybrid energy system, combining solar and wind energy, to power these systems and support the automation of greenhouse management.[8]

III. BLOCK DIAGRAM

Fig. (a) Block diagram Of Green House Automation

Working Principle of this block diagram



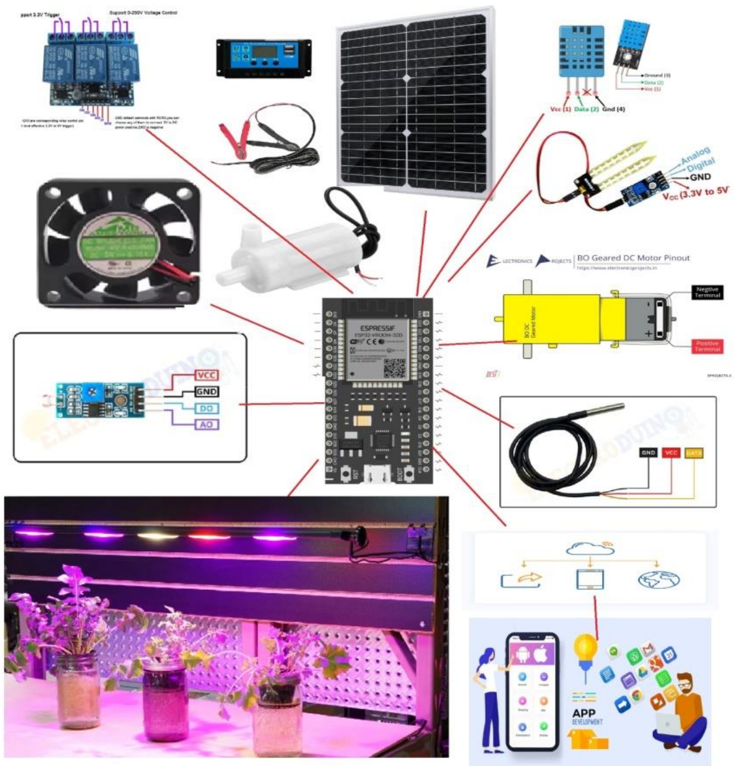
1. Power Supply
- The system is powered through a regulated power supply that provides the required voltage to the microcontroller (ESP8266/ESP32) and the connected sensors/actuators.

2. Sensor Inputs
- Temperature Sensor: Measures temperature levels and sends data to the microcontroller.
- Humidity Sensor: Measures humidity levels and sends the data.
- pH Sensor: Measures the pH level of a solution (e.g., water quality in irrigation or aquaculture).

3. ESP32
- This processes sensor data and makes decisions based on predefined conditions.
- If the temperature, humidity, or pH crosses a set threshold, it triggers outputs like Wi-Fi updates, alarms, or motor control.

4. Output Actions
- Wi-Fi Module: Sends real-time sensor data to a remote system, cloud storage, or mobile application for monitoring.

- Alarm: If sensor values go beyond limits, it triggers an alert.
- Driver Unit & Motor: Controls a motor based on sensor data. For example:
- In irrigation, if soil humidity is low, it turns on the water pump (motor).
- In water quality monitoring, if the pH is abnormal, corrective measures can be taken.



This image appears to represent a smart agriculture or hydroponics system using IoT technology. Below is an introduction to the components shown:

1. ESP32 Microcontroller (center) - The core of the system, responsible for processing data from sensors and controlling different devices via WiFi or Bluetooth.
2. Relay Module (top left) - Used for switching high-power electrical components like water pumps, fans, or lights.
3. Solar Panel & Charge Controller (top) - Provides power to the system using renewable energy.
4. DHT11/DHT22 Sensor (top right) - Measures temperature and humidity of the environment.
5. Soil Moisture Sensor (top right) - Detects moisture levels in the soil and helps in automating irrigation.
6. Fan (left) - Used for air circulation to maintain proper temperature and humidity.
7. Water Pump (left) - Pumps water to irrigate plants when needed.
8. B0 Geared DC Motor (right) - Can be used for automation, such as opening/closing a greenhouse window or controlling a robotic system.
9. DS18B20 Temperature Sensor (bottom right) - Measures the temperature of water or soil.
10. Light Module / LED Grow Lights (bottom left) - Provides artificial lighting to help plants grow indoors.
11. IoT & Mobile App Development (bottom right) - Represents the cloud-based monitoring system and mobile app integration for remote control.

These components together form a smart agricultural setup, enabling automated irrigation, climate control, and remote monitoring.

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Here is a detailed explanation of each circuit in this project, including how each component works, its connections, and its role in the system

1Power Supply System (Solar Panel, Charge Controller, and LM2596 Regulator)

Components:

20W Solar Panel (Provides DC power from sunlight)
Solar Charge Controller (Regulates battery charging)
12V Battery (Stores energy from the solar panel)
LM2596 Step-Down Regulator (Converts 12V to 5V for ESP32)
ESP32-WROOM-32 (Main microcontroller)

Working:

The 20W solar panel generates electricity from sunlight and sends it to the solar charge controller.
The charge controller manages power distribution and prevents overcharging of the 12V battery.
The battery supplies 12V DC to power motors, relays, and other high-power components.
The LM2596 step-down module converts 12V to 5V, which is required to power the ESP32 and sensors.

Connections:

Solar Panel → Charge Controller Input
Charge Controller Output (12V) → LM2596 Input
LM2596 Output (5V, GND) → ESP32 5V and GND Pins

2Motor Driver Circuit (L293D)

Purpose:

The L293D motor driver is used to control DC motors with the ESP32.
ESP32 cannot directly control high-power motors, so L293D acts as an interface.

Working:

The ESP32 sends control signals (HIGH/LOW) to the L293D motor driver to control motor direction and speed.
The L293D takes a 5V or 12V power supply to drive the motors.
INA1, INA2, INA3, INA4 are used to control two DC motors.

Connections:

L293D Pin	ESP32 Pin	Function
INA1	GPIO19	Motor 1 Direction
INA2	GPIO18	Motor 1 Direction
INA3	GPIO17	Motor 2 Direction
INA4	GPIO16	Motor 2 Direction
VCC1	5V	Logic Power
VCC2	12V	Motor Power
GND	GND	Ground

3 DS18B20 Temperature Sensor

Purpose:

Measures temperature and sends data to ESP32.

Working:

DS18B20 uses the 1-Wire communication protocol.
The ESP32 reads digital temperature values via GPIO32.
A 4.7KΩ pull-up resistor is required to stabilize the data signal.

Connections:

DS18B20 Pin	ESP32 Pin	Function
VCC	3.3V	Power Supply
GND	GND	Ground
DATA	GPIO32	Temperature Data

4DHT11 Temperature & Humidity Sensor

Purpose:

Measures both temperature and humidity.

Working:

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The sensor sends digital temperature and humidity values to ESP32.
Uses a single-wire communication protocol.
Connections:

DHT11 Pin	ESP32 Pin	Function
VCC	3.3V	Power Supply
GND	GND	Ground
DATA	GPIO23	Sensor Output

5 Relay Module (Controlling Devices)
Purpose:
The relay module controls high-power devices such as LED lights, fans, and pumps.
Working:
The ESP32 sends a HIGH or LOW signal to the relay to turn ON/OFF devices.
The relay acts as an electronic switch.
Connections:

Relay Function	ESP32 Pin	Function
LED Control	GPIO27	Turns LED ON/OFF
Cooling Fan	GPIO26	Controls Fan
Water Pump	GPIO25	Controls Pump

6 Soil Moisture Sensor
Purpose:
Measures soil moisture level to check if watering is needed.
Working:
The sensor outputs an analog value based on soil moisture.
The ESP32 reads this value via GPIO33.
Connections:

Soil Moisture Pin	ESP32 Pin	Function
VCC	5V	Power Supply
GND	GND	Ground
A0 (Analog)	GPIO33	Moisture Data

7 LDR (Light Dependent Resistor)
Purpose:
Detects light intensity for automatic light control.
Working:
The sensor outputs HIGH in darkness and LOW in bright light.
Connections:

LDR Module Pin	ESP32 Pin	Function
VCC	5V	Power Supply
GND	GND	Ground
DO (Digital Out)	GPIO14	Light Detection

8I2C LCD Display (16x2)
Purpose:
Displays sensor readings and system status.
Connections:

LCD I2C Pin	ESP32 Pin	Function
SDA	GPIO21	I2C Data Line
SCL	GPIO22	I2C Clock Line

9 HC-SR04 Ultrasonic Distance Sensor
Purpose:
Measures distance using ultrasonic waves.
Working:
ESP32 sends a pulse via TRIG pin.
The HC-SR04 emits ultrasonic waves.
The waves bounce back from an object.

The ECHO pin receives the signal and calculates distance.
Connections:

HC-SR04 Pin	ESP32 Pin	Function
VCC	5V	Power Supply
GND	GND	Ground
TRIG	GPIO4	Trigger Pulse
ECHO	GPIO36	Distance Data

10🔟 Rain Sensor

Purpose:
Detects rainfall intensity.
Working:
Outputs digital HIGH/LOW when rain is detected.
Provides an analog signal for rain intensity measurement.
Connections:

Rain Sensor Pin	ESP32 Pin	Function
VCC	5V	Power Supply
GND	GND	Ground
DO (Digital)	GPIO5	Detects Rain (ON/OFF)
AO (Analog)	GPIO34	Measures Rain Intensity

Application Areas

- Smart Agriculture: Automated irrigation based on soil conditions.
- Water Quality Monitoring: pH-based monitoring for aquaculture.
- IoT-based Monitoring: Wireless data transmission for real-time tracking.
- Climate Monitoring & Control
- Smart Irrigation & Water Management
- Automated Nutrient & Fertilizer Delivery

Advantages

- Remote Access & Control
- Real-Time Monitoring
- Higher Crop Yield & Quality
- Cost-Effective in the Long Run
- Energy Efficiency & Sustainability
- Smart Irrigation & Water Conservation
- Eco-Friendly Agriculture

IV.CONCLUSION

The Internate of Things(IoT)-based greenhouse monitoring and automation system powered by solar energy offers an innovative and sustainable approach to modern agriculture. By integrating IoT technology, real-time environmental data is collected, analyzed, and used to automate key greenhouse operations such as irrigation, ventilation, and lighting. This reduces manual labor, optimizes resource utilization, and enhances crop productivity.

The use of solar energy ensures that the system remains cost-effective and environmentally friendly, reducing reliance on conventional power sources. Additionally, remote monitoring capabilities allow farmers to make informed decisions, improving efficiency and overall yield.
In conclusion, this smart greenhouse system provides a scalable, energy-efficient, and sustainable solution for modern farming. It not only addresses the challenges of traditional greenhouse management but also supports precision agriculture, resource conservation, and long-term food security.

V. ACKNOWLEDGMENT

We would like to express our sincere gratitude to all those who contributed to the successful completion of this project on IoT-based Greenhouse Monitoring and Automation System Powered by Solar Energy.

Firstly, we extend our heartfelt thanks to our institution and faculty members for their invaluable guidance, encouragement, and technical support throughout this research. Their insights and expertise played a crucial role in shaping the direction of our work.

We also acknowledge the support of research organizations, industry experts, and online resources that provided essential knowledge and reference materials, helping us understand the latest advancements in IoT, automation, and solar energy applications in agriculture.

Finally, we appreciate the efforts of all individuals involved in the development and testing of this system, as their contributions have been instrumental in making this project a reality.

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