



Smart Greenhouse 5.0: IoT, AI, Data Science for Sustainable Farming

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Peer Review Information	Abstract
<p><i>Submission: 13 April 2026</i></p> <p><i>Revision: 05 May 2026</i></p> <p><i>Acceptance: 23 May 2026</i></p> <p>Keywords</p> <p><i>Optimization Control systems, Energy efficiency, Sustainable farming</i></p>	<p>In this project, our team built a Smart Greenhouse 5.0 system to deal with the issues of high labor costs and water waste." Using an ESP32 microcontroller as the brain of the system, we connected sensors to track soil moisture, heat, and light levels in real-time. Rather than constant manual monitoring, our system automatically turns on water pumps and cooling fans whenever the sensors show they are needed. We also built a web dashboard on laptop so the greenhouse can be monitored from a phone laptop. By adding a layer of AI for data analysis, the system helps predict exactly what the plants need before they show signs of stress. Our results show that this project makes farming much more efficient, saves a huge amount of water, and make sure crops grow in the best possible conditions.</p>

Introduction

Greenhouse agriculture plays an essential role in modern farming, providing controlled environments for year-round crop production. In contrast to traditional open-field farming, greenhouses enable growing conditions such as temperature, humidity, and CO₂ levels to be optimized, resulting in higher yields and better use of resources. This farming method reduces dependence on natural weather conditions, which is particularly crucial in regions with harsh climates. In addition, greenhouses enable sustainable practices by saving water through precision irrigation systems and minimizing land use compared to conventional agriculture. These advantages make greenhouse agriculture a key player in meeting global challenges such as food security, resource scarcity, and environmental sustainability.

Greenhouse systems vary considerably in complexity, offering different levels of automation and technological integration to meet the diverse needs of agricultural production. At the most basic level, traditional greenhouses rely on manual operations to

control environmental factors such as ventilation, shading, and irrigation. These systems are often economical and simple but lack the precision and efficiency needed to optimize crop yields and resource use. Although suitable for small farms or regions with limited technological access, traditional greenhouses are less adapt able to changing environmental conditions or resource constraints.

In contrast, semi-automated greenhouses incorporate basic technological components, such as temperature controlled ventilation, automatic shading, or timer-controlled irrigation systems. These systems reduce labor requirements and improve efficiency over manual methods, offering an intermediate solution for growers seeking higher productivity without the high costs associated with cutting-edge technologies. Innovation at the cutting edge includes smart greenhouses, Innovation at the cutting edge includes smart greenhouses, technologies such as IOT-based sensors, AI-driven systems, and sustainable energy solutions to create fully automated and self-regulating environment.. These systems

constantly monitor and adjust critical parameters such as temperature, humidity, CO2 levels, and soil moisture to ensure optimal growing conditions. Smart greenhouses represent a transformative approach to agriculture, offering significant advantages in terms of energy efficiency, water conservation, and scalability, making them essential to sustainable food Production in the face of global issues like increasing population and changing climatic conditions.

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The study showed by investigates the energy savings achieved by transitioning from HPS to LED lighting in green houses. LED lighting proves to be beneficial by reducing energy consumption for lighting; however, it increases the demand for heating, resulting in overall energy savings of 10– 25%. By automatically switching between sunlight and LED based on weather conditions, the system promotes this setup speeds up the growing cycle, meaning we get much better harvests in the end.

Furthermore, precise irrigation management is a crucial aspect of energy optimization in smart greenhouses. To save water, many systems now use drip-feed methods that provide a steady, controlled supply directly to each plant. Soil moisture sensors and control algorithms enable providing instant updates on the soil's moisture levels so we know exactly when to irrigate, avoiding unnecessary water losses and which cuts down the electricity needed to keep the water pumps running.

In addition, emerging modern farming is constantly evolving with new tools and systems in the field of modern greenhouses. For example, automated monitoring and control systems can be used to monitor and adjust greenhouse environmental conditions in real-time, enabling more efficient energy use. The system constantly checks the surrounding conditions, specifically temperature, humidity, light intensity, and air quality, while adaptive control systems adjust greenhouse parameters based on the collected data. The use of heat recovery systems can contribute to reducing energy losses by capturing and reutilizing the heat generated within the greenhouse.

The use of these advanced controllers in smart greenhouses offers several advantages. Firstly, they enable more precise and responsive regulation of environmental conditions, thereby maximizing energy efficiency and enhancing crop growth. Moreover, these controllers can adapt to changes occurring across different seasons, weather conditions, and specific crops

need to adapt control strategies accordingly. Finally, they provide increased flexibility and adaptability, allowing smart greenhouse operators to effectively manage variations and changes in the production environment.

Literature Review

The main goal of our research is to move away from old-fashioned farming and use digital tools to grow crops more effectively. We have designed a smart system that automates the daily chores of a greenhouse, which means a farmer doesn't have to be there every minute to check on the plants. A greenhouse is basically a shield that keeps crops safe from bad weather like heavy winds, hail, or too much sun, and it also keeps pests away.

In our project, we focused on precision. For example, instead of watering the plants on a timer, our system only turns on the pump when the sensors show the soil is actually dry. This saves a lot of water. We also look at how to keep the soil healthy by managing minerals like nitrogen and phosphorus using natural composting methods.

One big problem in India is that even though we have many rivers and plenty of rain, only about one-third of the farms are actually connected to a canal system. Most farmers have to rely on the monsoon or pump water from the ground, which often leads to wasting water. To fix this, our "Smart Greenhouse 5.0" uses a drip irrigation method to make sure we use every drop of water wisely.

The growth of the Internet of Things (IoT) has changed everything. Our paper explains how we built a greenhouse that you can monitor from anywhere in the world. We use three main control loops to manage the heat, moisture, and light inside the structure. This is all done using the ESP32 microcontroller and some custom software we wrote.

Data Science and Predictions

- **Linear Regression:** We applied Linear Regression as a primary mathematical tool to analyze the correlation between ambient heat and humidity levels. By processing the raw streams from the DHT11 sensor, this model allows the ESP32 to anticipate rapid climate shifts. For our project, this was essential for predicting how quickly the greenhouse would dry out after a cooling cycle, rather than just reacting to the data after it changes.

- **Random Forest Regression:** To achieve higher precision in our automated decisions, we implemented a Random Forest Regression model. Instead of a single decision path, this ensemble method evaluates multiple 'data trees'

Conclusion

The development of the Smart Greenhouse 5.0 successfully proves that low-cost IoT hardware, like the ESP32, can handle complex agricultural automation. During the testing phase, as seen in the real-time dashboard analytics, the system demonstrated high precision in monitoring critical variables—specifically maintaining temperature around 26°C and managing light intensity up to 15,000 Lux.

Unlike standard automated systems, the integration of AI-driven decision-making allowed the greenhouse to act preemptively. For instance, when soil moisture dropped below my calibrated 40% threshold, the logic loop immediately engaged the water pump without manual input, ensuring the plants never hit a wilting point.

This project isn't just a monitoring tool; it is a "plug-and-play" solution designed for scalability. The web-based interface provides a transparent view of the environmental trends, making high-tech farming accessible even to non-technical users. Ultimately, this research confirms that combining Python-based data science with IoT edge computing can significantly reduce resource waste and optimize crop productivity in modern urban farming settings.

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