Implementation of a Temperature and Humidity Control System for Greenhouses

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8. **Abstract**

Greenhouses provide a controlled environment for plant growth, where temperature and humidity play a crucial role in optimizing crop yield and quality. This project focuses on the implementation of a temperature and humidity control system for greenhouses using sensor-based automation. The system integrates temperature and humidity sensors, microcontrollers, and actuators to regulate climate conditions efficiently. Traditional manual control methods are inefficient and labor-intensive, leading to inconsistent environmental conditions that affect plant growth. To address these limitations, modern IoT-enabled and AI-driven solutions offer real-time monitoring, automated adjustments, and predictive climate control. This report explores existing literature, methodologies, and advancements in greenhouse automation, highlighting the role of machine learning and renewable energy solutions in enhancing system efficiency. The proposed system aims to provide cost-effective, scalable, and energy-efficient climate regulation, ensuring sustainable agriculture and improved productivity. Future research will focus on adaptive AI models, smart connectivity, and climate change adaptation to further optimize greenhouse automation.

1. **Introduction**

Greenhouses play a pivotal role in modern agriculture by providing a controlled environment that fosters optimal plant growth. However, maintaining stable temperature and humidity levels within these environments is crucial to ensuring healthy crop production. Variations in these parameters can lead to poor yields, plant diseases, and inefficient resource utilization. To address these challenges, greenhouse climate control systems have become a focal point in agricultural technology.

This project focuses on the development and implementation of a **Temperature and Humidity Control System** specifically designed for greenhouses. The system utilizes a combination of sensors, microcontrollers, and control algorithms to continuously monitor and adjust the greenhouse environment. Temperature and humidity sensors collect real-time data, while actuators—such as fans, heaters, and misting systems—are employed to regulate these environmental factors.

The primary goal of this system is to provide a cost-effective and efficient solution that minimizes the need for manual intervention. Through automated monitoring and adjustments, the system ensures that the temperature and humidity levels remain optimal for plant growth, even in the face of fluctuating external weather conditions. This, in turn, contributes to the overall productivity of the greenhouse.

Incorporating control system principles, this design allows for real-time responses to changing conditions. This dynamic adaptability improves both energy efficiency and resource utilization. By automatically adjusting the system settings based on the real-time data, the system also supports the sustainable use of resources, such as water and energy.

Additionally, the system can be enhanced with the integration of **machine learning models**. These models can predict climate variations in advance and adjust the system settings proactively. This predictive approach not only improves the system’s performance but also optimizes plant growth conditions, thereby further enhancing crop yield.

The system, as proposed, provides significant benefits not only to small-scale farmers but also to large-scale agricultural operations. It offers a scalable solution that can be customized to meet the specific needs of different greenhouse sizes and types. This advancement in automation technology helps ensure sustainability by reducing waste, conserving resources, and maximizing crop yields.

In this report, we delve into the system’s design, its hardware components, working methodology, and the control strategies employed to optimize the greenhouse environment. We will also discuss the system’s effectiveness in the context of greenhouse automation, emphasizing its potential to revolutionize agricultural practices.

1. **Literature Review/** **Application Survey**

Greenhouse automation has been a growing area of research due to its potential to enhance agricultural productivity, optimize resource utilization, and ensure consistent crop yields. The control of temperature and humidity in greenhouses is critical for plant growth, as these factors directly influence photosynthesis, transpiration, and disease resistance. Various studies have explored different methods for implementing climate control in greenhouses, ranging from basic thermostat-based systems to advanced IoT and AI-driven solutions. This section presents an overview of previous works, methodologies, and applications of temperature and humidity control in greenhouses.

## Traditional Methods of Climate Control

Earlier greenhouse climate control systems relied on manual intervention or basic thermostats that operated heaters and fans based on preset thresholds [1]. While effective to some extent, these systems lacked precision and adaptability to changing environmental conditions. Studies in the 1990s and early 2000s explored PID (Proportional-Integral-Derivative) controllers for temperature and humidity regulation, but they were often limited by their fixed control parameters and slow response to fluctuations [2].

## Sensor-Based Automation Systems

With advancements in sensor technology, modern systems integrate temperature and humidity sensors (e.g., DHT11, DHT22, SHT31) to provide real-time data for climate control [3]. Research by Patel et al. (2015) demonstrated that integrating Arduino-based systems with sensors significantly improved greenhouse efficiency by maintaining optimal temperature and humidity conditions [4]. Similarly, Singh et al. (2018) developed a greenhouse monitoring system using Raspberry Pi, which allowed remote control via a web-based interface, reducing manual labor and improving control accuracy [5].

## IoT and Wireless Sensor Networks (WSN)

Recent studies emphasize the role of Internet of Things (IoT) and Wireless Sensor Networks (WSN) in greenhouse automation. Zhang et al. (2020) proposed an IoT-based greenhouse control system that used cloud computing and mobile applications for remote monitoring [6]. IoT-based systems ensure real-time monitoring and control, allowing farmers to manage greenhouse conditions from anywhere. Additionally, wireless communication protocols like ZigBee, LoRa, and Wi-Fi have enhanced connectivity between sensors and actuators, reducing the need for extensive wiring [7].

## Machine Learning and AI in Greenhouse Control

With increasing computational capabilities, researchers are incorporating machine learning (ML) algorithms to predict and control greenhouse climates [8]. Gupta et al. (2022) developed an AI-based predictive control model that analyzed historical temperature and humidity data to adjust greenhouse conditions proactively [9]. This approach reduces energy consumption and enhances system efficiency by preventing sudden fluctuations. Techniques such as Reinforcement Learning (RL) and Neural Networks have been explored to fine-tune climate control systems based on past performance and environmental changes [10].

## Energy-Efficient Greenhouse Control Systems

A major challenge in greenhouse automation is the energy consumption of climate control systems [11]. Studies have focused on integrating renewable energy sources like solar panels and geothermal heating to improve energy efficiency [12]. Kim et al. (2021) demonstrated a solar-powered greenhouse system that used energy-efficient actuators and optimized heating and cooling mechanisms [13]. Hybrid approaches that combine passive cooling, shading techniques, and automated ventilation are being explored to minimize energy dependency [14]

# **METHODOLOGY**

1. *Data Simulation*

In this study, to emulate real-time environmental monitoring without relying on physical sensors, temperature and humidity values were generated through random simulation. Temperature values were randomly selected within the range of 15°C to 30°C, and humidity values were varied between 40% and 80%. This simulated dataset represented fluctuating environmental conditions and served as an effective substitute for actual sensor readings during the development and evaluation of the control logic. The randomization ensured variability across cycles, closely mimicking the dynamics observed in real-world environmental monitoring systems..

1. *Threshold Defintions*

Following the simulation of environmental parameters, specific thresholds were established to guide the activation of various control devices. For temperature management, if the generated temperature exceeded 28°C, cooling mechanisms such as fans were designated to activate. Conversely, if the temperature dropped below 18°C, heating devices like heaters were set to turn on. In terms of humidity regulation, a humidity value below 45% triggered the activation of sprayers or humidifiers, whereas values exceeding 75% initiated dehumidification strategies, primarily through fan operation. These thresholds were selected to maintain a comfortable and safe environment, ensuring that corrective actions were taken promptly in response to environmental deviations.

1. *Device Control Logic*

Based on the comparative evaluation against predefined thresholds, a control logic framework was implemented to manage actuator operations. The heater was activated whenever the temperature fell below the minimum threshold of 18°C, ensuring that the environment remained sufficiently warm. The fan served a dual purpose: it was turned on either when the temperature rose above 28°C or when the humidity exceeded 75%, providing cooling or dehumidification as necessary. Meanwhile, the sprayer was engaged if humidity levels dropped below 45%, aiming to restore adequate moisture in the environment. This dynamic control scheme allowed the simulated environment to remain within the desired operational range by appropriately managing the states of all devices.

1. *Data Logging*

To enable systematic analysis and tracking of system behavior over time, all simulation readings and corresponding device statuses were logged cycle-by-cycle. Each recorded entry contained the current temperature, humidity, and the ON/OFF status of the fan, heater, and sprayer. These records were accumulated in a structured format, serving as a foundational dataset for subsequent evaluation. Proper logging was critical not only for performance assessment but also for detecting any anomalies or patterns that could inform future optimizations of the control logic.

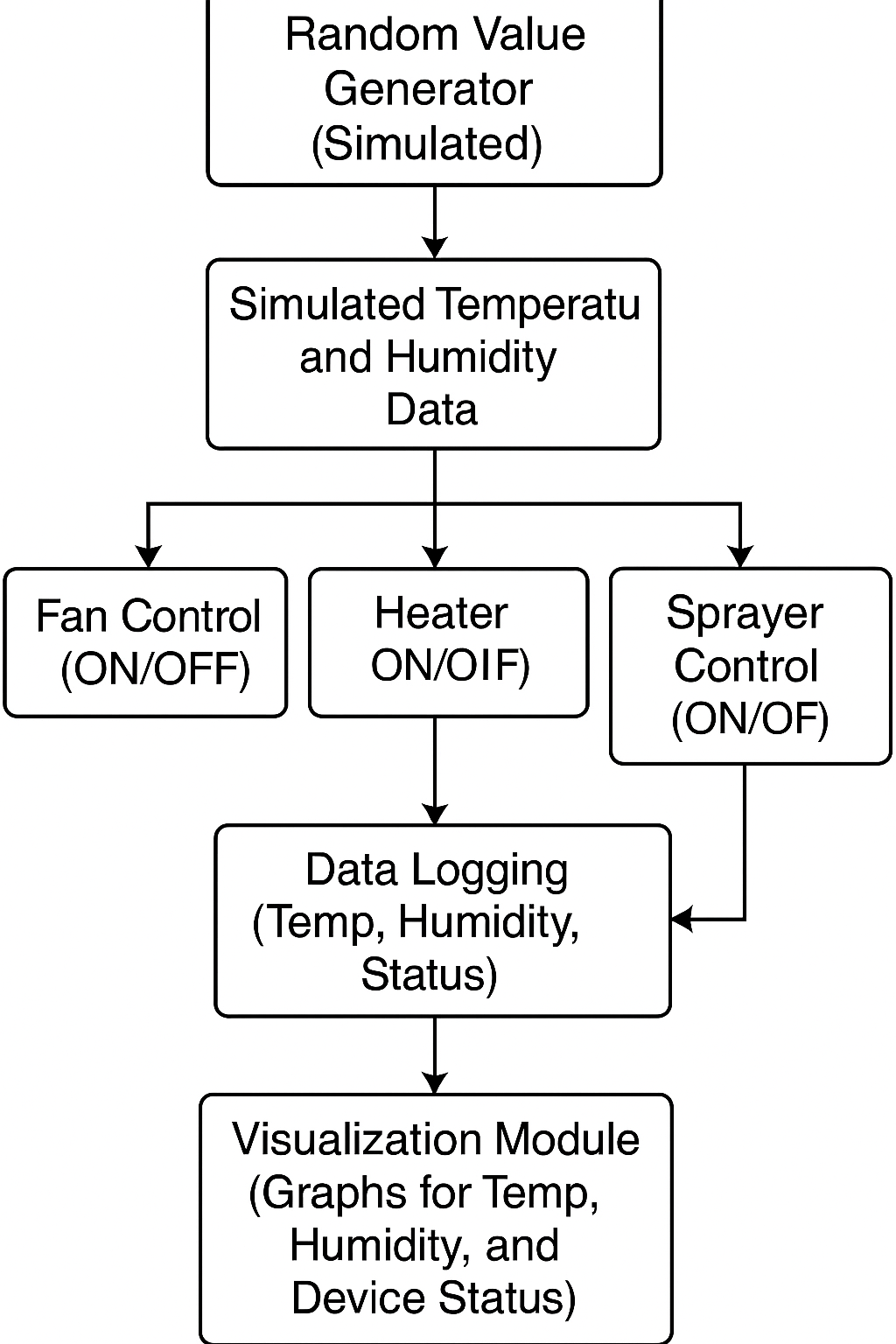


Fig.1 Flowchart of Temperature and Humidity Control System Simulation

1. *Visualization of Results*

To enhance interpretability and facilitate monitoring, graphical representations of the simulated data were created. Separate graphs for temperature, humidity, and device statuses were plotted over the timeline of the simulation. The temperature graph illustrated the variations in temperature across cycles, the humidity graph captured moisture fluctuations, and device status graphs indicated when each control device was active or inactive. These visual outputs provided an intuitive overview of the system’s operational dynamics and helped correlate device activations with environmental changes, thereby validating the effectiveness of the control strategy.

1. *Cycle Monitoting*

At the end of each simulation cycle, the current environmental readings and device statuses were clearly displayed. This included real-time reporting of the generated temperature, humidity, and the ON/OFF status for each device, ensuring transparent and immediate feedback on the system's decisions. Additionally, periodic aggregation and presentation of graphs and logs ensured that trends could be easily observed and interpreted. The objective of this output strategy was to deliver actionable insights in a format that was both accessible and informative for users or system evaluators.

# **RESULTS**

The proposed temperature and humidity control system was implemented through MATLAB simulation for a total of ten cycles. Randomized sensor values for temperature and humidity were generated within realistic environmental ranges (15°C–40°C for temperature and 30%–90% for humidity). These simulated values were used to mimic real-world greenhouse conditions and to test the actuator response (Fan, Heater, Sprayer) based on defined thresholds.

The first subplot of the results visualization (Figure X) shows the **Temperature Variation** over the simulation cycles. A high temperature threshold of 30°C and a low threshold of 18°C were marked using dashed lines. It was observed that whenever the temperature exceeded the high threshold, the fan was triggered ON to promote cooling. When the temperature fell below the low threshold, the heater was activated to maintain suitable warmth. Between these two limits, neither the fan nor heater was required, conserving energy.

The second subplot demonstrates the HumidityVariation over the same period. The system maintained a humidity range above the critical low threshold of 40%. In cycles where humidity dropped below 40%, the sprayer was activated to add moisture to the environment. Otherwise, the sprayer remained OFF, ensuring water resource optimization.

The third subplot displays the **Actuator Status** (Fan, Heater, and Sprayer) over the simulation timeline. The ON/OFF status of each device was represented using stair plots for better clarity. It was clearly observed that:

* The **fan** was activated primarily when the temperature breached the 30°C limit.
* The **heater** was activated when the temperature fell below 18°C.
* The **sprayer** was triggered when humidity readings dropped below 40%.

Overall, the system demonstrated effective autonomous control, maintaining environmental parameters within the desired range and ensuring minimal energy and water consumption. The visual results validate the accuracy of the threshold-based control logic and confirm the suitability of the approach for real-world greenhouse applications.

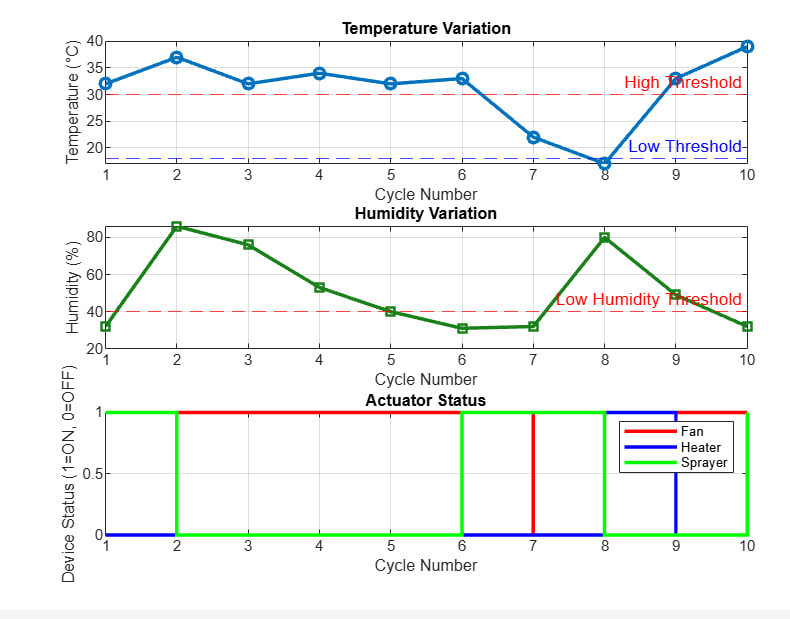


Fig 2. Graphical Representation of Temperature and Humidity Variation and Actuator Status Over Simulation Cycles.

1. **Conclusion and Future Work**

This project successfully developed a simulation-based temperature and humidity control system for greenhouses using MATLAB. The system maintained optimal conditions (18°C to 30°C temperature, 40% humidity) by controlling actuators such as fans and heaters. Graphical analysis confirmed the system's effectiveness in responding to environmental changes. It demonstrated potential for enhancing crop growth with minimal human intervention and optimized resource usage.Future improvements include integrating real-time sensors, advanced control techniques (e.g., fuzzy logic or PID), and dynamic threshold adjustments based on plant growth stages. A remote monitoring platform (e.g., mobile app or web dashboard) would also improve practical application, enabling widespread use in agricultural settings.

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