

Design, Implementation, and Field Testing of an Automated Greenhouse Monitoring and Control System

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Abstract: Greenhouse crop production requires strict environmental regulation to ensure optimal plant growth, reduce losses, and enhance yield consistency. Traditional manual monitoring methods often fail to maintain stable microclimatic conditions, leading to inefficiencies in both resource use and plant performance. This study presents the complete design, implementation, and field testing of an automated greenhouse monitoring and control system developed using low-cost sensors, microcontroller-based data acquisition, wireless communication modules, and locally coded control algorithms. The system continuously tracks temperature, humidity, soil moisture, and light intensity while automatically activating ventilation, irrigation, and shading mechanisms based on preset thresholds. A three-month field experiment was conducted in a semi-controlled greenhouse environment to evaluate reliability, responsiveness, and agricultural impact. Results demonstrate a 36 percent improvement in temperature stability, a 42 percent reduction in water waste, and a 28 percent increase in average crop growth rate compared to conventional manual control. Data logs confirm high sensor accuracy and effective integration of control loops. The system's modular design, low cost, and adaptability make it suitable for small- and medium-scale growers, especially in regions lacking advanced agricultural infrastructures. Findings show that automated greenhouse systems can significantly enhance productivity while reducing operational complexities and resource consumption.

Keywords: greenhouse automation, environmental monitoring, IoT control system, smart agriculture, microclimate regulation

1. Introduction

Greenhouse cultivation provides controlled environments capable of supporting intensive agriculture, but maintaining reliable microclimatic conditions remains a persistent challenge for growers. Factors such as fluctuating temperatures, inconsistent irrigation cycles, and unpredictable weather patterns can negatively affect plant health and yield. Automated greenhouse systems have emerged as a promising technology-driven solution, integrating sensors, microcontrollers, and communication networks to measure and regulate environmental factors in real time. Previous research has demonstrated the usefulness of such systems for increasing crop yields and reducing manual labor [1], yet many existing designs remain too expensive or complex for small-scale farmers. This research aims to design and test a low-cost, fully automated greenhouse monitoring and control system using commercially accessible components and open-source programming. The system focuses on maintaining ideal temperature, humidity, soil moisture, and light conditions, offering practical applicability in diverse climatic regions.

2. Methodologies

The greenhouse automation system was designed using a modular architecture built around an Arduino Mega microcontroller and supported by DHT22 temperature-humidity sensors, soil-moisture probes, and BH1750 light

sensors. Data was recorded at ten-second intervals and transmitted through an ESP8266 Wi-Fi module to a cloud dashboard for live monitoring. The control mechanisms included an automated drip-irrigation pump, a servo-based ventilation window actuator, and a motor-controlled shading curtain. All actions were governed by rule-based logic comparing real-time sensor data with user-defined thresholds, such as 60 percent soil moisture, 32°C maximum air temperature, and 40,000 lux light intensity limits. The system was deployed inside a 4m x 6m polycarbonate greenhouse for a duration of ninety days during which environmental stability, sensor accuracy, system responsiveness, and crop growth (tomato and lettuce plants) were evaluated. Manual greenhouse operation was used as a comparative baseline.[Fig. 2]



Fig. 1 Automated Greenhouse Control System

3. Results

The Data obtained during the field experiment show that the automated system successfully maintained stable environmental conditions across all monitored parameters. Temperature fluctuations were reduced by 36 percent, with the system activating ventilation precisely whenever internal temperatures exceeded the upper threshold. Soil-moisture consistency greatly improved, reducing over-irrigation incidents observed in the manually controlled greenhouse and lowering total water usage by 42 percent. Light intensity regulation through automated shading minimized leaf scorching in tomato plants, improving overall growth rate by 28 percent. The cloud dashboard achieved a 98.6 percent successful data-upload rate, confirming high system reliability. Irrigation pump activation and ventilation control occurred with an average delay of less than 2.1 seconds. These results confirm that low-cost automated control produces substantial improvements in environmental regulation and plant productivity when compared to traditional manual management methods [2].

4. Discussion

The performance evaluation demonstrates that automated monitoring considerably enhances greenhouse efficiency, particularly with respect to irrigation, thermal control, and consistent light management. The system's microcontroller-based logic effectively responds to real-time conditions, reducing the need for constant human intervention. The use of low-cost sensors did not significantly affect accuracy, aligning with similar studies that validated the use of affordable components for agricultural automation [3]. Water savings highlight the system's sustainability benefits, while improved crop performance suggests a direct relationship between environmental stability and plant physiology. The modular design also supports the integration of advanced IoT analytics, predictive modeling, and machine-learning-based crop-health detection in future expansions.

5. Uses of the Automated Greenhouse System

The developed system demonstrates several practical applications useful across a wide range of agricultural contexts. Farmers can deploy it in small-scale or commercial greenhouses to improve crop reliability while reducing daily labor requirements. Its real-time monitoring capability enables early detection of environmental deviations, preventing crop stress and minimizing losses. Since the system optimizes irrigation, it is especially beneficial in water-scarce regions where resource efficiency is critical. Educational institutions may use the platform to train students in agricultural automation, IoT systems, and climate-smart farming. The design may further be adapted for nurseries, seedling propagation units, hydroponic farms, and research-based plant-growth chambers requiring precise environmental regulation.

6. Conclusion

This study successfully designed, implemented, and field-tested a low-cost automated greenhouse monitoring and control system capable of maintaining stable environmental conditions and enhancing plant growth. The performance evaluation confirms significant improvements in temperature regulation, irrigation efficiency, and crop vitality when compared to manual intervention. The modular architecture, scalability, and minimal operating costs position the system as a practical solution for both small-scale and developing-region agricultural environments. Future research may focus on integrating predictive algorithms, solar-powered operation, and AI-driven disease detection for further improvements in greenhouse productivity.

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