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Design and Implementation of Microcontroller-Based Climate Control System for Smart Greenhouse Applications

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INTRODUCTION & AIM

The rapid growth of the global population and the increasing effects of climate change are exerting strong pressure on agricultural systems. Traditional open-field farming faces constraints such as irregular rainfall, soil degradation, and limited arable land. Greenhouse cultivation has therefore become a strategic approach for ensuring stable and high-yield crop production in controlled environments [1].

Despite its advantages, greenhouse farming requires continuous regulation of microclimatic conditions. Critical factors such as temperature, relative humidity, carbon dioxide (CO_2) concentration, and light intensity strongly influence plant growth, photosynthetic efficiency, and overall yield. Manual control of these parameters is often inefficient, leading to resource overuse, increased costs, and reduced crop quality.

The integration of digital technologies, especially embedded systems, offers promising opportunities. Microcontrollers combined with environmental sensors and automatic actuators can enable real-time monitoring and regulation of greenhouse conditions [2]. These tools contribute to precision agriculture and sustainable intensification, helping farmers optimize inputs while minimizing environmental impacts [3].

The aim of this study is to design, implement, and experimentally validate a microcontroller-based climate control system for smart greenhouse applications.

METHOD

The climate control platform was developed using an Arduino Mega 2560 R3 microcontroller as the central processing unit [2]. The system integrates multiple environmental sensors:

- Temperature and Humidity Sensor (DHT22) for monitoring ambient conditions.
- CO_2 Sensor (MG-811) for detecting carbon dioxide concentration.
- Light Sensor (LDR or BH1750) for measuring light intensity.

A set of actuators was connected to regulate the environment:

- Ventilation fans for air circulation.
- Humidifiers/dehumidifiers for controlling relative humidity.
- CO_2 injection module for gas enrichment.
- Artificial lighting to supplement natural light.

The sensors provide continuous real-time data to the Arduino board. A feedback control algorithm processes the inputs and activates the actuators accordingly to maintain predefined threshold values.

In addition, the system was interfaced with a desktop application designed for data acquisition, visualization, and user interaction. This interface allowed operators to set environmental parameters, monitor performance, and log data for analysis [4].

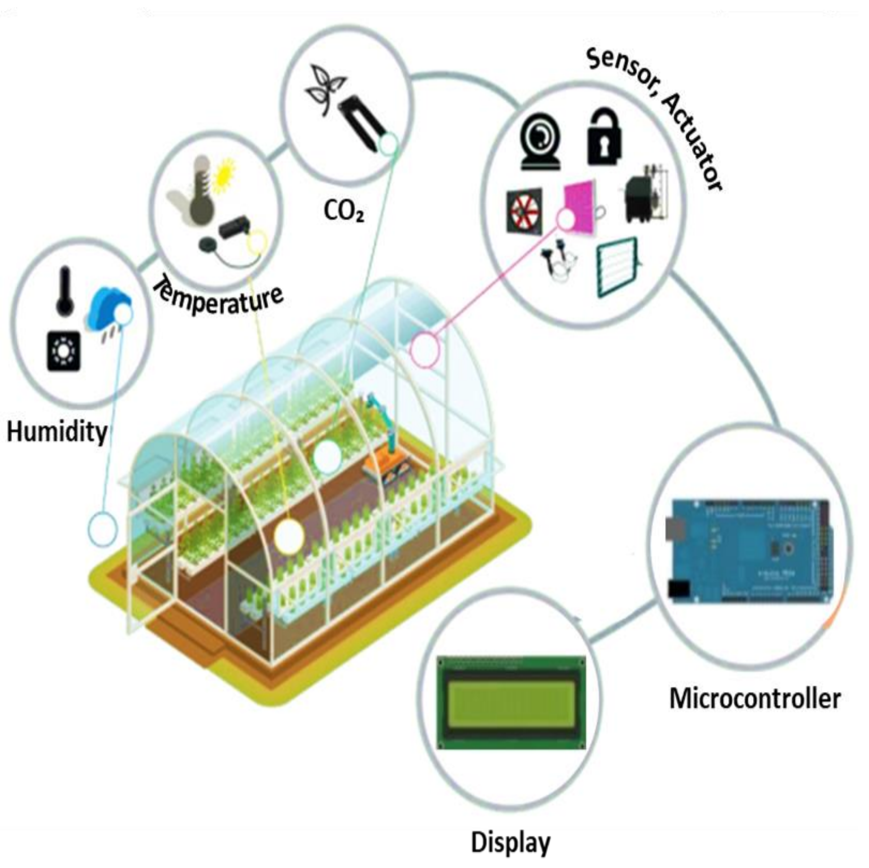

Figure 1: Climatic parameters.

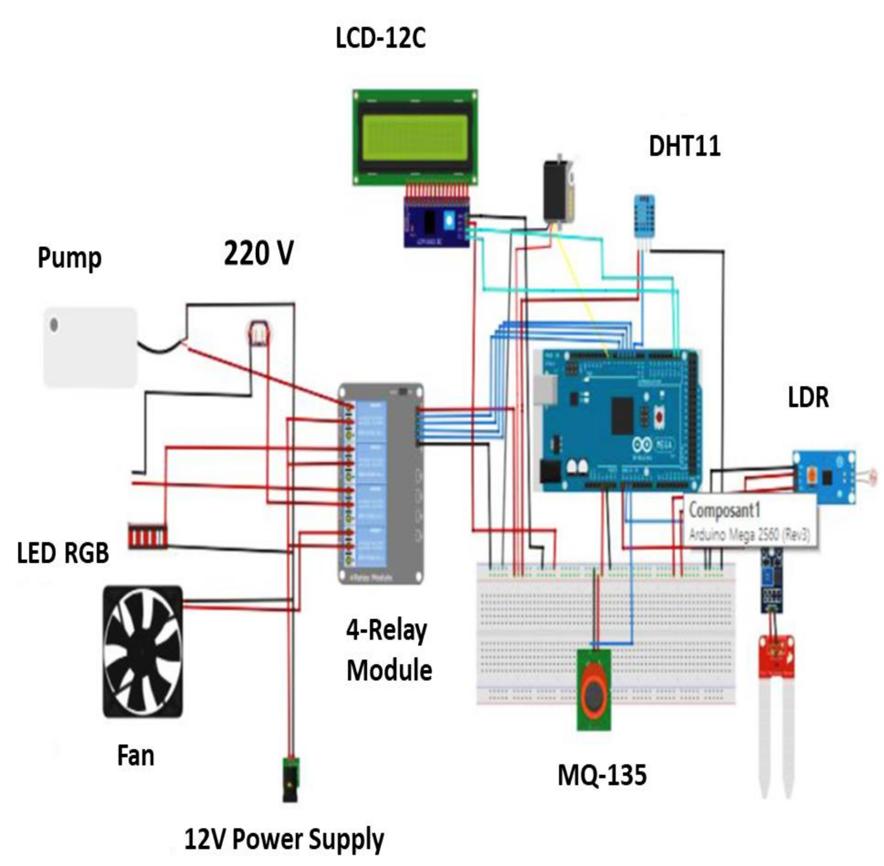

Figure 2: Electronic Schematic of the System Based on Arduino Mega 2560.

RESULTS & DISCUSSION

The proposed system was assembled and tested under experimental greenhouse conditions. Key findings include:

- The feedback control algorithm successfully regulated microclimatic parameters within acceptable ranges for optimal plant growth.
- The system achieved real-time adjustments, with response times ranging between 5–10 seconds depending on the parameter monitored.
- The platform demonstrated energy efficiency, as actuators were only activated when sensor readings crossed threshold values.
- Compared with manual control, the system reduced human intervention by more than 70% and improved consistency of environmental conditions.

The low cost of the components (Arduino board, sensors, actuators) makes the system accessible and scalable for small and medium-sized agricultural enterprises. However, further optimization is needed for large-scale commercial greenhouses where environmental fluctuations are more complex [5].

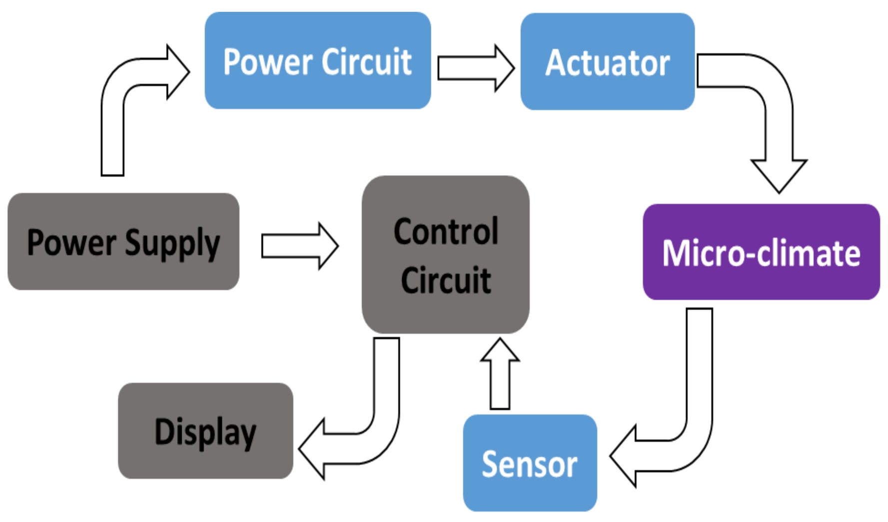

Figure 3: Block Diagram of an Affordable Smart Greenhouse Control System.

Figure 4: Smart farming greenhouse prototype

CONCLUSION

This study presented the design and validation of a microcontroller-based automated climate control system for greenhouse management. The results confirmed that the system is cost-effective, reliable, and adaptable to different greenhouse setups.

It represents a practical contribution to the adoption of smart agriculture technologies in regions facing climatic uncertainty and limited resources.

FUTURE WORK

Future perspectives include:

- Integration of Internet of Things (IoT) connectivity for remote monitoring [5].
- Use of wireless sensor networks (WSNs) for distributed data collection.
- Application of artificial intelligence (AI) and machine learning algorithms for predictive climate control [3].
- Expansion to hydroponic and aquaponic systems for further optimization of resource use.

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