“Smart AI-Powered Greenhouse with Computer Vision for Plant Monitoring and Adaptive Climate Control”

Abstract

In this project, we present the design and development of a miniature smart greenhouse equipped with artificial intelligence and IoT capabilities. The system uses an Arduino microcontroller to control environmental conditions such as temperature, humidity, and soil moisture using sensors (DHT11 and soil moisture sensor), water pumps, and fans. Data is displayed locally via an LCD and transmitted wirelessly using an ESP8266 module for remote monitoring and control.

A camera module powered by computer vision and a lightweight machine learning model enables plant type identification and yellow leaf detection, allowing for adaptive control strategies tailored to each plant's specific needs. Our system is designed to be low-cost, energy-efficient, and scalable for educational, research, or small-scale agricultural use. Initial tests show promising results in plant health monitoring and environmental regulation.

1. Introduction

Climate change and population growth have significantly increased the demand for efficient and sustainable agricultural solutions. Traditional greenhouses often require manual intervention and lack the precision needed for optimal plant growth. In recent years, smart agriculture has emerged as a promising field that combines sensors, automation, and artificial intelligence to monitor and control environmental conditions.

In this project, we designed and built a miniature smart greenhouse system to demonstrate how modern technology can improve plant care. Our system combines Arduino-based hardware, wireless communication, and AI-powered computer vision to automate irrigation, ventilation, and humidity control. Unlike conventional setups, our greenhouse adapts to the specific needs of different plants by identifying them and monitoring their health—particularly through detecting yellow leaves as a sign of stress or disease.

This work serves both as a practical solution for small-scale gardening and as an educational platform to explore the intersection of hardware, programming, and artificial intelligence.

2. Related Work

Smart greenhouse systems have gained significant attention in recent years due to their ability to optimize plant growth while reducing human labor. Several projects and studies have focused on integrating sensors and automation to control environmental parameters such as temperature, humidity, and soil moisture. These systems often rely on microcontrollers like Arduino or Raspberry Pi and provide remote monitoring through wireless modules.

However, many existing designs lack advanced decision-making capabilities. Most systems are either rule-based or require manual input to respond to plant needs. While some research has applied AI to greenhouse automation, few have implemented real-time plant recognition and health monitoring using computer vision.

What distinguishes our project is the integration of a lightweight computer vision model capable of identifying plant types and detecting yellow leaves, enabling adaptive responses based on the plant's current status. This level of automation allows the greenhouse to respond intelligently to changing conditions, without human intervention, making it more efficient and scalable.

3. System Design

The smart greenhouse system is built around the Arduino Uno microcontroller, which coordinates the operation of various sensors, actuators, and communication modules. The following components are integrated into the system:

DHT11 sensor: Measures air temperature and humidity.

Soil moisture sensor: Monitors the soil's water content.

Water level sensor: Detects the water level in the reservoir.

Relay-controlled fans and water pumps: Manage ventilation and irrigation based on sensor readings.

LCD display: Provides real-time data on environmental conditions.

ESP8266 Wi-Fi module: Enables wireless data transmission and remote control via a web or mobile interface.

Camera module: Captures plant images for processing by a machine learning model that identifies plant types and detects yellowing leaves.

The control logic is implemented in **C++** on the Arduino, with thresholds for temperature, humidity, and soil moisture that trigger fans or pumps automatically. The camera module sends images to a lightweight AI model, which classifies the plant and determines its needs. Based on the identified plant type and health status, the system adjusts environmental controls accordingly.

Power is supplied through a standard DC source, and the system can run continuously or be scheduled for specific cycles using programmable timers.

4. AI Model & Image Processing

To enhance the system's intelligence, a compact machine learning model is deployed for real-time plant recognition and leaf health detection. The camera module captures periodic images of the plants, which are then processed using a lightweight convolutional neural network (CNN).

Model Capabilities:

- **Plant type classification:** The model is trained to identify common plant species using a labeled dataset.
- **Yellow leaf detection:** It detects color changes in leaves, especially yellowing, which can indicate nutrient deficiencies, disease, or watering issues.

The model is trained offline using Python and TensorFlow, then optimized and deployed on a local edge device (e.g., Raspberry Pi or ESP32-CAM). The edge deployment ensures that the system can function independently without needing cloud access, which is especially important in remote or low-connectivity environments.

Once the model analyzes the image, it sends feedback to the Arduino controller. Based on the plant type and health status, the system automatically adjusts the watering schedule, humidity control, and ventilation.

5. Conclusion

This smart greenhouse project showcases the powerful combination of embedded systems, sensor integration, wireless communication, and artificial intelligence to create an efficient and responsive plant care system. By automating temperature control, humidity regulation, irrigation, and plant health monitoring, the system reduces human intervention and supports optimal plant growth.

The integration of machine learning allows the greenhouse to go beyond fixed rules and adapt to different plant species and their specific needs, making it ideal for educational, experimental, or small-scale agricultural purposes.

This project not only demonstrates practical applications of AI and IoT but also serves as a foundation for more advanced systems with cloud connectivity, mobile apps, and real-time analytics in the future.