IOT-ENABLED SMART GREENHOUSE MANAGEMENT: INTEGRATING BIOFEEDBACK SYSTEMS AND SUSTAINABLE PRACTICES FOR ENHANCED AGRICULTURAL EFFICIENCY

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Keywords:

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Introduction:

Agriculture is one of the most important sectors for human survival. With the growing population, there is a need to increase food production using modern technology. Traditional farming methods require a lot of manual work and constant monitoring, which is not always efficient or reliable. To solve this problem, we have designed a smart greenhouse system using IoT and deep learning. This project helps farmers monitor and manage the greenhouse automatically. It uses sensors like temperature, soil moisture, rain, smoke, flame, and ultrasonic to keep track of the environment. Based on the sensor values, devices like water pumps, fans, and LED lights are turned on or off. The system is powered by solar panels connected to a battery, making it eco-friendly and cost-effective. This ensures the greenhouse can work even in areas without a regular power supply. Apart from monitoring, we also added a leaf disease detection system using a Raspberry Pi and a camera. The Pi captures images of plant leaves and checks if the plant is healthy or infected. We collected 1,011 images of leaves and classified them into three categories: healthy, bean rust, and leaf miner. We trained models like DenseNet121, MobileNetV2, and VGG19 to identify these diseases. The best model is used in the system to give real-time results. This project helps reduce manual work, saves resources, and improves plant health. It is especially useful for small-scale farmers looking for smart and affordable solutions.

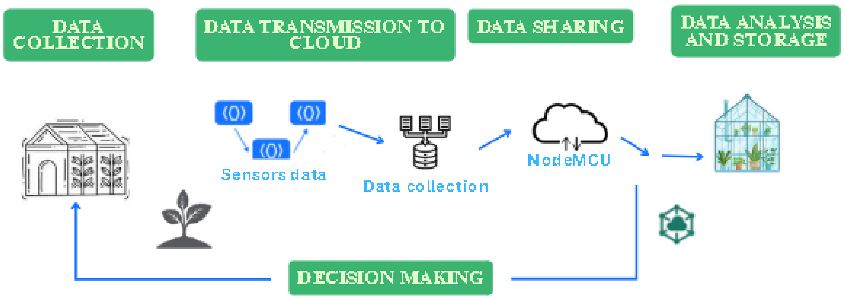

Figure 1: *Basic Workflow of Greenhouse Monitoring Objectives*

The Figure 1 illustrates the basic workflow of the IoT-based smart greenhouse monitoring system. It starts with data collection from various sensors placed in the greenhouse, which monitor parameters like temperature, soil moisture, humidity, and more. This sensor data is then transmitted to the cloud using wireless modules for remote access. The data is collected and sent through a microcontroller (such as NodeMCU), enabling data sharing over the internet. Once in the cloud, the information is analysed and stored, allowing the system to understand the environmental conditions inside the greenhouse. Based on this analysis, the system makes automated decisions—such as turning on the water pump, fan, or lights—to maintain ideal growing conditions for the plants. The cycle continues, ensuring continuous monitoring and smart decision-making for healthy and efficient crop production.

Objectives:

1. To design and implement an IoT-based smart greenhouse system that can automatically monitor and control environmental parameters such as temperature, soil moisture, rainfall, smoke, and fire for optimal plant growth.

2. To develop a deep learning-based plant disease detection model using Raspberry Pi and a camera module that can classify leaf images into healthy or diseased categories (bean rust, leaf miner) in real-time.

3. To integrate the IoT system with the disease detection model to provide a fully automated, eco-friendly, and low-cost solution for small and medium-scale farmers to improve productivity and plant health.

Methodology:

The project is divided into two main parts: the IoT-based smart greenhouse system and the deep learning-based disease detection system. First, we set up the greenhouse environment using various sensors such as temperature, soil moisture, rain, flame, smoke, and ultrasonic sensors. These sensors constantly collect real-time data from the greenhouse. Based on this data, actions are taken automatically. For example, if the soil is dry, the water pump is turned on. If the temperature is too high, the fans are activated. If there is low natural light, LED bulbs provide extra light. All these devices are powered using a solar panel connected to a battery, which ensures the system runs even during power cuts. The microcontroller like ESP32 is programmed to read sensor data and control the devices. The readings can also be sent to a mobile or web-based IoT dashboard for monitoring. For the second part, a Raspberry Pi with a camera module is placed inside the greenhouse to capture plant leaf images regularly. We collected a dataset of 1,011 images of long yard bean leaves. These images were categorized into three classes: healthy, bean rust, and leaf miner. The images were pre-processed and used to train deep learning models such as DenseNet121, MobileNetV2, and VGG19. After comparing their accuracy and performance, the best model was selected and deployed on the Raspberry Pi. When the Raspberry Pi captures a new image, the model checks the leaf condition and identifies if any disease is present. If a disease is detected, an alert is generated to notify the user. This complete system helps farmers monitor greenhouse conditions and detect plant diseases in real-time without manual effort.

Result and Conclusion:

The developed smart greenhouse system successfully monitored and controlled the internal environment using IoT sensors and automation. The system responded well to real-time changes in temperature, soil moisture, and light levels, activating devices like the water pump, fans, and LED bulbs as needed. The use of solar power made the setup energy-efficient and ideal for remote areas. On the deep learning side, the Raspberry Pi effectively captured leaf images and ran disease detection in real time. Among the models tested, DenseNet121 gave the highest accuracy, followed by VGG19 and MobileNetV2. The deployed model was able to correctly classify leaf images into healthy, bean rust, or leaf miner classes with good reliability. The integration of both systems provided a complete solution for greenhouse automation and crop health monitoring. Alerts and notifications helped users take quick actions to control diseases and improve productivity. In conclusion, the project proves that combining IoT and deep learning can greatly benefit agriculture. It reduces manual effort, saves resources, and helps farmers manage their crops in a smarter and more sustainable way.

Project Outcome & Industry Relevance:

The project successfully demonstrated how IoT and deep learning can work together to create a fully automated and intelligent greenhouse system. It showed that environmental conditions like temperature, humidity, and soil moisture can be continuously monitored and controlled without human intervention. The disease detection system also performed well, accurately identifying common leaf diseases using real-time images. In real-world scenarios, this system can be highly beneficial for farmers, especially in rural or remote areas where access to expert help is limited. By receiving early alerts, farmers can take immediate action to protect crops, reduce losses, and improve yield. The solar-powered setup makes it sustainable and cost-effective for long-term use. Industries working in smart farming, agricultural automation, and precision agriculture can adopt this model to improve efficiency and crop health. The project contributes to the on-going research in sustainable agriculture and AI-driven farming solutions, helping bridge the gap between technology and traditional farming practices.

Working Model:

The proposed project integrates an IoT-enabled smart greenhouse monitoring system with a deep learning-based plant disease detection model to create an intelligent and automated environment for sustainable agriculture. The smart greenhouse system is equipped with a variety of sensors including temperature sensors, soil moisture sensors, rain sensors, ultrasonic sensors, MQ2 gas/smoke sensors, flame sensors, and actuators like water pumps, exhaust fans, and LED bulbs. The system continuously monitors environmental parameters such as temperature, humidity, soil moisture, rainfall, smoke, and fire, and performs automated actions like irrigation, ventilation, and artificial lighting based on predefined thresholds, thus maintaining optimal conditions for plant growth. In addition to environmental monitoring, the system also features a disease detection module implemented using deep learning. A Raspberry Pi with an attached camera module is used to capture real-time images of plant leaves within the greenhouse. A dataset comprising 1,011 images of long yard bean leaves was collected and categorized into three classes: bean rust, healthy, and leaf miner. These images were pre-processed and used to train three convolutional neural network models: DenseNet121, MobileNetV2, and VGG19. The trained models were evaluated for accuracy and performance, and the best-performing model was deployed on the Raspberry Pi for real-time inference. Upon detecting any disease, the system generates alerts and logs the information, helping farmers take timely action. This integrated approach not only automates greenhouse management but also enhances crop health monitoring, making it a cost-effective and scalable solution for small and medium-scale farmers.

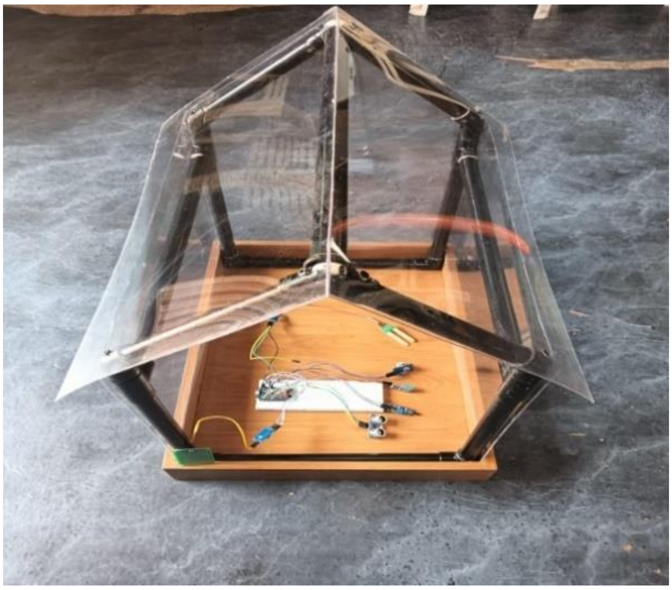

Figure 2: IoT Based Greenhouse

The Figure 2 shows a mini model of a smart greenhouse used for testing and demonstration purposes. The structure is made of a transparent sheet supported by a lightweight frame to resemble a real greenhouse environment. Inside the greenhouse, various sensors are installed on a wooden base. These sensors are used to monitor key environmental parameters such as temperature, soil moisture, humidity, and more. The setup allows data to be collected in real-time and processed through a microcontroller to control devices like fans, water pumps, and lights. This model helps simulate how the full-scale IoT-based smart greenhouse system would function, ensuring plants are grown under optimal conditions automatically.

Project Outcomes and Learnings:

This project successfully integrates IoT technology with deep learning to create an efficient and automated greenhouse monitoring system. The outcomes include a fully functioning system that monitors environmental conditions, automates greenhouse tasks, and detects plant diseases in real-time. The use of solar power ensures sustainability, and the automated processes help reduce water and energy consumption. By implementing deep learning models like DenseNet121, MobileNetV2, and VGG19 for disease detection, the system can accurately classify plant health, offering timely alerts to farmers. This minimizes crop loss by enabling early intervention. The project also demonstrated the power of combining IoT with machine learning to address real-world agricultural challenges. Through hands-on work, we gained valuable experience in sensor integration, data collection, and training AI models. We also learned the importance of optimizing models for real-time applications on resource-constrained devices like Raspberry Pi. Ultimately, this project reinforces the potential of smart farming solutions to improve efficiency, sustainability, and productivity in agriculture.

Future Scope:

The future scope of this project includes:

- Integration of Weather Prediction Systems: Enhance responsiveness to environmental changes like temperature shifts and sudden rainfall.
- Addition of Advanced Sensors: Include pH sensors for soil quality and CO_2 sensors for air quality to optimize growing conditions.
- Predictive Machine Learning Models: Implement models that forecast plant growth and yield based on environmental and historical data.
- Expansion of Disease Detection Capabilities: Extend the system to detect a broader range of plant diseases across multiple crop types.
- Larger and Diverse Datasets: Use more comprehensive datasets to improve the accuracy and robustness of deep learning models.

- Blockchain Integration: Use blockchain for transparent tracking of crop origin, health history, and supply chain quality.
- Support for 5G and Edge Computing: Leverage faster connectivity and local processing for real-time monitoring and scalable deployment in larger farms.