Optimizing Greenhouse Conditions for Strawberry Cultivation through AIoT Environmental Monitoring and Automation

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Abstract

This paper presents an innovative AIoT (Artificial Intelligence of Things) project focused on optimizing greenhouse conditions for strawberry cultivation through advanced monitoring, analysis, and intervention strategies. Leveraging Artificial Intelligence (AI) and Internet of Things (IoT) technologies, the project integrates environmental monitoring sensors to regulate crucial parameters like temperature, humidity and brightness. Additionally, the project incorporates drone-based image capture and Convolutional Neural Network (CNN) analysis to detect illnesses in strawberry plants. The system autonomously analyzes the captured images to identify early signs of diseases or nutrient deficiencies, providing timely recommendations for targeted interventions. By combining environmental optimization with proactive disease management and nutrient supplementation, this AIoT solution offers a holistic approach to enhancing crop yield, quality, and sustainability in greenhouse farming of strawberries.

1 Introduction

Greenhouse farming offers a controlled environment for cultivating crops, allowing for year-round production and optimization of growing conditions. In the context of strawberry cultivation, maintaining optimal environmental parameters such as temperature, humidity, and light level is crucial for maximizing yield and quality. However, ensuring the health and vigor of strawberry plants goes beyond merely regulating environmental factors; it also involves proactive disease management and nutrient supplementation.

In this paper, we introduce a comprehensive IAoT (Intelligent Automation of Things) project aimed at revolutionizing greenhouse farming of strawberries through advanced monitoring, analysis, and intervention strategies. Building upon the foundation of environmental monitoring and automation, our project incorporates innovative technologies such as drone-based image capture and Convolutional Neural Network (CNN) analysis to detect illnesses in strawberry plants.

By deploying drones equipped with high-resolution cameras as additional sensors within the greenhouse environment, we capture detailed images of the strawberry plants at regular intervals. These images are then processed using CNN algorithms to detect early signs of illnesses or abnormalities in plant health. Through the analysis of plant morphology, color variations, and other visual cues, the system can identify potential issues such as fungal infections, nutrient deficiencies, or pest infestations.

Furthermore, our IAoT system is designed to go beyond mere detection by providing actionable insights to the farmer. Upon detecting signs of illness or nutrient deficiencies, the system generates recommendations for targeted interventions, such as the application of specific supplements or vitamins to address the identified issues. These recommendations are based on a combination of historical data, expert knowledge, and machine learning algorithms, allowing for personalized and timely interventions tailored to the specific needs of each plant.

By integrating drone-based image capture and CNN analysis into our IAoT framework, we aim to enhance the overall health, productivity, and resilience of strawberry crops grown in greenhouse environments. This holistic approach to crop management not only improves yield and quality but also promotes sustainability by reducing the reliance on chemical inputs and minimizing crop losses due to diseases or nutrient deficiencies. Through the synergy of AI, IoT, and advanced sensing technologies, our project represents a significant step towards the future of precision agriculture in greenhouse farming.

2 AIoT for Precision Agriculture

The future of agriculture is intelligent. By merging Artificial Intelligence (AI) with the Internet of Things (IoT), we're ushering in an era of precision agriculture. This powerful combination allows farmers to optimize crop growth, maximize yields, and minimize environmental impact.

Here's how AIoT transforms agriculture:

Real-time monitoring: A network of sensors collects data on vital factors like temperature, humidity, soil moisture, and nutrient levels. AI-powered analysis: Advanced algorithms analyze this real-time data, identifying areas for improvement and predicting potential issues. Data-driven decisions: Farmers receive actionable insights, allowing them to precisely adjust irrigation, fertilization, and pest control strategies. The benefits are numerous:

Increased efficiency: Precise resource allocation minimizes waste, leading to significant cost savings. Improved sustainability: Reduced water usage, optimized fertilizer application, and targeted pest control contribute to a greener agricultural footprint. Enhanced yields and quality: By creating optimal growing conditions, AIoT helps produce higher yields of superior quality crops. AIoT empowers farmers with:

Remote monitoring and control: Manage your greenhouse or farm from anywhere. Early disease detection: AI can identify signs of illness before they spread, minimizing crop loss. Automated processes: Automate tasks like irrigation and ventilation, freeing up valuable time. The future of AIoT in agriculture is bright:

Advanced sensors: Development of low-cost, multifunctional sensors will further enhance data collection capabilities. Global connectivity: Advancements like LEO constellations will provide seamless internet access in remote areas. Massive IoT: Scaling up sensor networks will enable precision agriculture across vast fields, maximizing its impact. By embracing AIoT, we can create a future where agriculture is not only productive but also sustainable. Let's cultivate a world of abundance while safeguarding our planet for generations to come. Selected resources for smart/intelligent greenhouses were presented under Table 1.

Resource	**Purpose**
Temperature control system	Regulation of heating, cooling, and ventilation to prevent frost, fungi, and bacteria growth and ensure optimal crop growth.
Illuminance, ground, multimedia, climate, radiation and tag sensors	Remote identification, remote image capture, light monitoring for plant growth, analytic and reasoning functionality, information mining and equipment control, as well as early climate warning.
Decision support system (DSS)	Farm-specific semantic annotation and interoperability.

Table 1: Selected resources for smart greenhouses (Singh et al., 2020).

3 Industry 4.0: The Foundation for Smart and Sustainable Agriculture

The rise of Industry 4.0, characterized by smart technologies and data-driven processes, has significantly impacted agriculture. This transition, often referred to as Agriculture 4.0 and 5.0, is fueled by the integration of innovative tools like AI, Big Data, UAVs (uncrewed aerial vehicles), and the Internet of Things (IoT) into farm operations.

Here's how Industry 4.0 principles are shaping the future of agriculture:

Precision Farming: AI and data analysis empower farmers to make informed decisions about resource allocation, leading to closed-loop control and optimized use of water, fertilizers, and other resources (Saiz-rubio, 2020; Katamreddy et al., 2019; Madushanki et al., 2019). Sustainable Practices: By promoting efficient resource utilization in controlled environments like greenhouses (Popović et al., 2017; Syafarinda et al., 2018; Raviteja and Supriya, 2020; Ruan et al., 2020), Agriculture 4.0 contributes to environmental sustainability and aligns with global sustainable development goals (Cisco and the International Telecommunication Union (ITU), 2015). Improved Food Supply Chains:

Traceability becomes a reality with IoT integration, enabling better monitoring and management of food production processes (He and Shi, 2021). This translates to improved food safety and efficiency within supply chains (Sinha, Shrivastava, and Kumar, 2019).

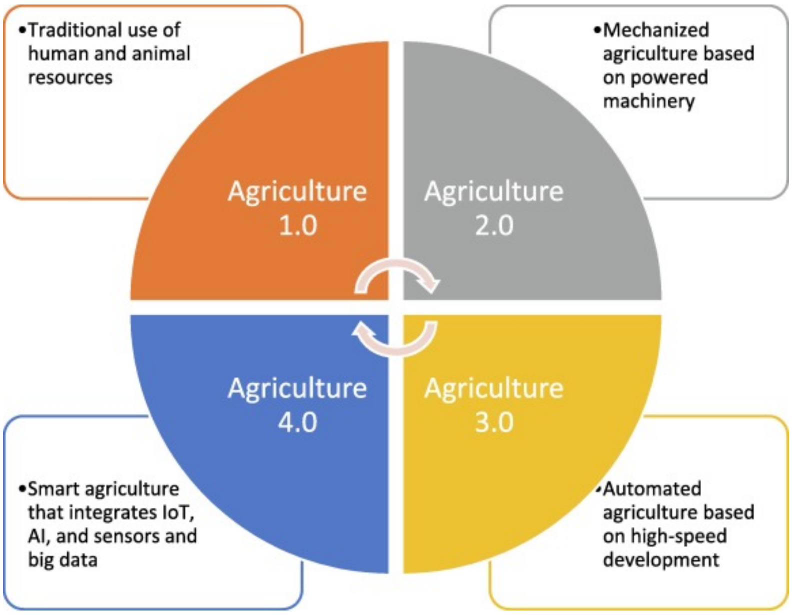

Figure 1: Increase in agricultural complexity with advances made from Agriculture 1.0 to Agriculture 4.0 (Friha et al., 2021).

The transition to Agriculture 4.0, initiated around 2017 (Friha et al., 2021), represents a significant leap forward. It signifies the integration of big data analytics, drone technology (Jumaah et al., 2021), IoT networks, and AI-powered machine learning (Friha et al., 2021). This technological revolution is driven by the need to adapt to climate change challenges (Environmental Protection, 2020) and ensure a more sustainable and efficient agricultural sector.

However, unlocking the full potential of Agriculture 4.0 requires the extensive adoption and integration of these advanced technologies into farming practices. Further research and critical analysis are needed to optimize energy, water, and e-waste management, address environmental concerns, improve IoT protocols, and facilitate a smooth digital transformation within the agricultural sector.

4 Project Design

4.1 Environmental Monitoring System

Our environmental monitoring system utilizes a range of sensors strategically placed within the greenhouse to capture crucial data points essential for optimal strawberry cultivation. These sensors include:

- **Temperature Sensors**
  Temperature regulation plays a pivotal role in ensuring optimal growing conditions for strawberries. To this end, our environmental monitoring system incorporates high-precision temperature sensors strategically distributed throughout the greenhouse. These sensors monitor ambient temperature levels with precision, enabling proactive adjustments to maintain temperatures within the ideal range conducive to strawberry growth and development. By capturing variations across different zones within the greenhouse, our temperature sensors afford granular insights essential for precision agriculture management.

- **Humidity Sensors**
  Humidity levels profoundly impact plant health and productivity, with deviations from the optimal range posing risks such as mold proliferation and impaired transpiration. Our humidity sensors continuously monitor atmospheric moisture content, providing real-time data essential for mitigating potential risks and optimizing growing conditions. By leveraging insights gleaned from humidity sensor data, stakeholders can proactively implement measures to regulate humidity levels and ensure an optimal microclimate for strawberry cultivation.

- **Light Level Sensors**
  Light serves as a primary driver of photosynthesis, exerting a profound influence on plant growth and development. Our environmental monitoring system integrates light level sensors to gauge the intensity and duration of sunlight within the greenhouse environment. These sensors facilitate precise monitoring of natural light conditions, enabling stakeholders to optimize artificial lighting interventions if necessary. By ensuring adequate

illumination levels, our light level sensors empower growers to maximize photosynthetic efficiency and optimize yield potential.

4.1.1 System Architecture

The architecture of the AIoT framework encompasses an intricate interplay of multifaceted components meticulously orchestrated to orchestrate a seamless continuum of data acquisition, analysis, and action. At its core, the system comprises IoT-enabled sensors meticulously positioned within the greenhouse environment to capture an array of critical parameters including temperature, humidity, and light intensity. These sensor nodes interface with a sophisticated AI prediction model engineered to extrapolate future conditions based on historical data patterns and real-time inputs. Subsequently, the predictive insights gleaned from the model inform the dynamic control of actuators governing pivotal greenhouse variables such as irrigation and illumination.

4.1.2 Data Generation and AI Model

In our project, the generation of accurate and representative environmental data is paramount for training an effective AI model. We simulated environmental conditions pertinent to strawberry cultivation, including temperature, humidity, and light intensity, ensuring that the generated data reflects the dynamic nature of greenhouse environments. This simulated data was then stored in a structured format, such as a CSV file, for use in model training and evaluation.

For the AI model, we employed a multi-output regression approach, leveraging the scikit-learn library in Python. This model was trained to predict two crucial outputs: the desired light level and the watering duration based on the input environmental parameters. By training on historical data patterns and real-time inputs, the AI model learns to extrapolate future conditions, enabling proactive decision-making in greenhouse management. The model's ability to capture complex relationships between environmental factors and optimal actions is essential for ensuring efficient and sustainable cultivation practices.

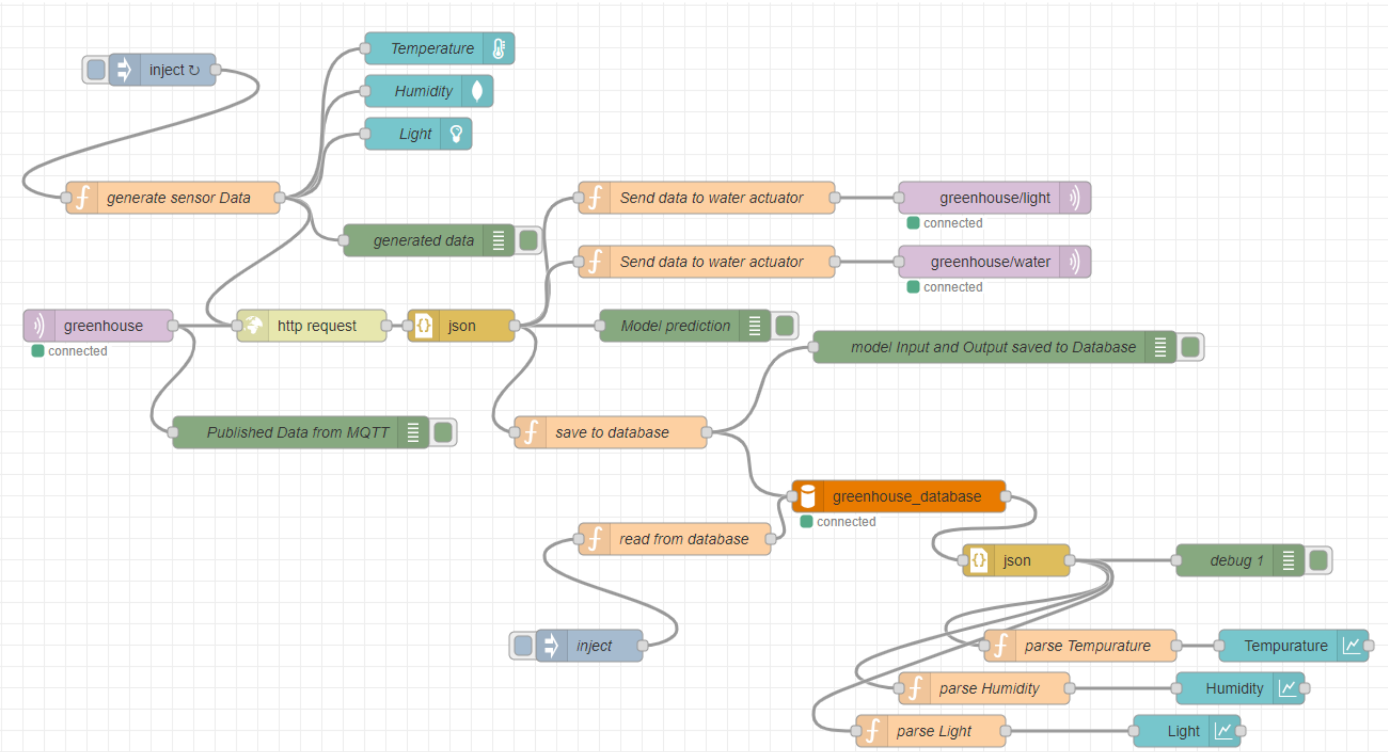

Figure 2: Screenshot showcasing the nodes of the smart greenhouse system, each equipped with various sensors and IoT devices for monitoring and controlling environmental conditions.

4.1.3 Implementation

Sensor Deployment and Data Acquisition: Strategically positioned IoT sensors serve as the cornerstone of the AIoT framework, capturing a diverse array of environmental parameters critical to plant growth and development. Sensors are meticulously deployed within the greenhouse environment to ensure comprehensive coverage, with each sensor interfacing seamlessly with the broader system infrastructure.

FastAPI Integration for AI Model Deployment: The implementation leverages FastAPI, a high-performance web framework for building APIs with Python, to facilitate the seamless integration of AI prediction models into the AIoT ecosystem. FastAPI's inherent speed and scalability empower the framework to handle concurrent requests with exceptional efficiency, thereby facilitating real-time prediction and analysis. Additionally, the system incorporates an HTTP Request Node, which facilitates communication with external endpoints for sensor data exchange and model predictions. This node serves as a crucial link between the FastAPI-based AI model deployment and other components of the AIoT framework, enabling seamless data flow and interaction between disparate system elements.

MQTT Protocol for Communication: The MQTT protocol serves as a pivotal communication backbone within the AIoT framework, facilitating seamless data exchange between disparate system components. MQTT's lightweight and publish-subscribe architecture ensure efficient message transmission, enabling real-time insights to be disseminated across the ecosystem.

MySQL Database Management: Critical to the system's intelligence is the MySQL database management system, which facilitates the storage and retrieval of sensor data, model predictions, and actuation commands. MySQL's relational database architecture ensures robust data management, enabling retrospective analysis and iterative refinement of greenhouse management strategies.

Dashboard: An intuitive visualization interface is integrated into the system, providing stakeholders with real-time insights into crucial environmental parameters. The dashboard allows for seamless monitoring of temperature, humidity, and light intensity levels within the greenhouse. Through interactive charts, graphs, and data tables, users can gain deeper insights into environmental conditions, facilitating informed decision-making and proactive management strategies.

Actuation and Control Mechanisms:

- **Dynamic Actuation based on Predictive Insights**
  Actuators embedded within the greenhouse infrastructure dynamically adjust environmental conditions based on predictive insights gleaned from the AI model. These actuators are orchestrated to modulate parameters such as irrigation, lighting, and ventilation, ensuring optimal growing conditions tailored to the specific requirements of the cultivated crops.

- **Feedback Mechanisms for Iterative Optimization**
  The AIoT framework incorporates feedback mechanisms to facilitate iterative optimization of greenhouse management strategies. Actuation commands are continually refined based on real-time sensor data and model predictions, enabling adaptive responses to evolving environmental dynamics and crop needs.

Security and Scalability Considerations:

- **End-to-End Security Protocols**
  Security protocols are integrated into every layer of the AIoT framework to safeguard data integrity and system resilience. Encryption algorithms, access controls, and intrusion detection mechanisms mitigate the risk of unauthorized access or malicious attacks, ensuring the confidentiality and integrity of sensitive agricultural data.

- **Scalability and Interoperability**
  The AIoT framework is architected with scalability and interoperability in mind, enabling seamless integration with existing agricultural infrastructure and facilitating future expansion. Modular design principles and standardized communication protocols facilitate interoperability with diverse sensor networks and agricultural management systems, thereby accommodating the evolving needs of precision agriculture initiatives.

Ethical and Regulatory Considerations: Ethical and regulatory considerations underpin the design and deployment of the AIoT framework, ensuring adherence to established norms and guidelines governing data privacy, environmental sustainability, and agricultural ethics. Transparent data collection practices, informed consent protocols, and adherence to industry standards serve as foundational pillars, fostering trust and accountability within the precision agriculture ecosystem.

Performance Evaluation and Optimization: The performance of the AIoT framework is systematically evaluated through rigorous testing and validation procedures, encompassing metrics such as system responsiveness, prediction accuracy, and resource utilization efficiency. Performance optimization techniques, including algorithmic refinement and hardware optimization, are employed iteratively to enhance system efficacy and reliability in real-world deployment scenarios.

4.2 Drone-based Disease Detection

In this component of our project, we implement a drone-based disease detection system to augment the environmental monitoring capabilities of the greenhouse. The system employs drones equipped with high-resolution cameras to capture aerial imagery of the strawberry plants within the greenhouse. These drones follow a predefined flight pattern optimized for comprehensive coverage of the cultivation area while minimizing overlap.

The frequency of image capture is optimized based on factors such as plant growth stage, disease prevalence, and resource constraints. Images are captured at regular intervals, typically ranging from daily to weekly, to monitor changes in plant health and detect early signs of diseases or nutrient deficiencies.

Prior to analysis, captured images undergo preprocessing techniques to enhance the quality and suitability for CNN analysis. These preprocessing steps may include resizing, color correction, noise reduction, and image segmentation to isolate individual plant components for analysis.

4.2.1 Disease Detection with CNNs

Convolutional Neural Networks (CNNs) are well-suited for image analysis tasks due to their ability to automatically learn hierarchical features from raw pixel data. In this component of our project, we leverage CNNs to detect and classify diseases affecting strawberry plants based on visual symptoms observed in the captured aerial imagery.

The training process of the CNN model involves the following steps:

- **Dataset Collection:**
  A labeled dataset of healthy and diseased strawberry plant images is curated, encompassing a diverse range of disease symptoms and severity levels.

- **Data Augmentation:**
  To mitigate overfitting and improve model generalization, data augmentation techniques such as rotation, flipping, and cropping are applied to increase the diversity of training samples.

- **Model Training:**
  The CNN model is trained using the curated dataset, where the input images serve as the input data and the corresponding disease labels serve as the target outputs. The model learns to extract relevant features from the input images and classify them into predefined disease categories.

- **Validation and Fine-tuning:**
  The trained model is evaluated on a separate validation dataset to assess its performance and identify potential areas for improvement. Fine-tuning techniques such as adjusting hyperparameters, modifying network architecture, and incorporating transfer learning from pre-trained models may be applied to optimize model performance further.

Once trained, the CNN model can be deployed alongside the environmental monitoring system to automatically analyze aerial imagery captured by the drones. By detecting and classifying diseases in real-time, growers can promptly implement targeted interventions to mitigate disease spread and minimize crop losses.

5 Results and Discussion

Initial assessment of the automated greenhouse management system demonstrated its effectiveness in maintaining optimal growing conditions for strawberry cultivation. Unlike conventional solutions that rely solely on IoT for data collection and actuation, our proposed system integrates AI and IoT technologies to provide a smarter and more proactive approach to greenhouse management. By leveraging predictive insights from historical data and real-time sensor inputs, our system dynamically controls actuators to optimize pivotal greenhouse variables such as irrigation and illumination. This innovative approach ensures that the system adapts to changing environmental conditions and provides precise recommendations for achieving the optimal light level and watering duration for strawberry cultivation. By combining AI and IoT, our solution not only enhances the efficiency and effectiveness of greenhouse management but also facilitates data-driven decision-making for sustainable agriculture practices.

6 Conclusion and Future Scope

In conclusion, our AIoT project represents a paradigm shift in greenhouse farming, offering a holistic approach to optimizing strawberry cultivation through advanced monitoring, analysis, and intervention strategies. By leveraging AI and IoT technologies, we enable growers to create and maintain optimal growing conditions, detect early signs of diseases or nutrient deficiencies, and implement targeted interventions to promote plant health and productivity.

Through the integration of Node-RED integration, and database management, our system provides growers with actionable insights and recommendations for sustainable crop management. By embracing the principles of precision agriculture and Industry 4.0, we pave the way for a future where farming is not only productive but also environmentally sustainable and resilient.

Future directions include:

- Expanding the scope of the AIoT system to other crops and greenhouse environments
- Integrating additional sensors and data sources for comprehensive monitoring and analysis
- Enhancing the AI models with advanced techniques such as deep learning and reinforcement learning
- Collaborating with industry partners and stakeholders to deploy the AIoT system on a larger scale and evaluate its impact on crop yield, quality, and sustainability.

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