

A Comprehensive Literature Survey on IoT-Based Smart Greenhouse Automation

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Abstract— Conventional greenhouse cultivation relies heavily on manual observation of environmental and plant conditions, which can be time-consuming and may delay the detection of plant stress or disease. Recent developments in sensing, wireless communication, automation, artificial intelligence and computer vision provide opportunities to make greenhouse management more proactive and efficient. This paper proposes AgriSync, a smart greenhouse monitoring and automation system designed to integrate environmental monitoring, predictive irrigation, climate management, plant disease detection and adaptive lighting control within a coordinated architecture. The proposed system collects information related to soil conditions, temperature, humidity, light and other plant-growth parameters, along with periodic plant images, and processes the collected data to support automated decisions and recommendations. The system is intended to control irrigation, ventilation and supplemental lighting while providing users with real-time information, alerts and analytical insights. The paper reviews relevant research works, identifies limitations in existing standalone approaches, and presents AgriSync as a low-cost integrated framework intended for future prototype development and experimental validation.

Keywords — IoT, Smart Greenhouse, Artificial Intelligence, Predictive Irrigation, Computer Vision, Wireless Communication, Automated Greenhouse Control, Adaptive Lighting.

I. INTRODUCTION

Greenhouse cultivation provides a controlled environment for crop production by reducing dependence on unpredictable outdoor conditions and enabling effective management of factors such as temperature, humidity, soil moisture and light intensity. However, conventional greenhouses still rely considerably on manual monitoring, which can be time-consuming, inconsistent and unable to provide continuous observation. This may delay the detection of environmental variations, water stress and early symptoms of plant disease. Therefore, sustainable greenhouse cultivation requires systems capable of continuously monitoring environmental and plant conditions and responding to undesirable changes.

Monitoring alone is not sufficient for effective greenhouse management. Appropriate actions such as irrigation, ventilation and supplemental lighting are required when unfavourable conditions are detected. Depending on manual intervention can delay these responses. Modern greenhouse systems therefore integrate monitoring, analysis and automated control to provide a more responsive approach to crop management.

Advances in sensing technologies, wireless communication, artificial intelligence, predictive analysis and computer vision have improved greenhouse automation. These technologies enable prediction of water requirements, plant disease detection, environmental analysis and recommendation of suitable control actions. Adaptive lighting can also supplement natural light according to plant growth requirements. However, many existing systems focus on individual functions such as monitoring, irrigation, disease detection or lighting. The limited integration of these functions creates a need for a coordinated greenhouse management system capable of making decisions based on multiple environmental and plant-related conditions simultaneously.

II. LITERATURE REVIEW

A. IoT-Based Greenhouse Monitoring and Communication

Recent studies demonstrate the importance of sensor-based monitoring and reliable communication in smart greenhouse systems. Bouarroudj et al. [1] developed an autonomous greenhouse system that monitors environmental and soil-related parameters and uses cloud communication for data management and fault detection. Dinn et al. [2] proposed a multi-stage architecture consisting of sensor nodes, a communication layer, a processing unit and a visualisation platform. Similarly, [3] highlights the suitability of long-range, low-power communication for greenhouse applications where conventional wireless connectivity may be limited. These studies support the use of an architecture where the pathway goes from sensor to the gateway and then to the main processing unit which indicates the need for improved integration between monitoring and automated control.

Based on these studies, we have integrated sensor-based environmental monitoring, wireless communication and a sensor to processing architectural pathway into the proposed system.

B. Predictive Irrigation and Soil Monitoring

Instead of responding only to the current soil conditions, predictive irrigation aims to estimate future water requirements. Ye et al. [4] proposed a prediction-based irrigation method which is capable of maintaining soil moisture near the desired level while reducing unnecessary irrigation. Similarly, [5] demonstrates the use of prediction-based monitoring for controlling greenhouse actuators. These studies show that with predictive approaches one can maintain more efficient water management than conventional threshold-based irrigation, although most reported implementations remain limited to small-scale experimental environments. Based on these studies, we have integrated predictive irrigation and soil moisture-based water management into the proposed system. This approach aims to maintain suitable moisture conditions while minimizes the unnecessary usage of water.

C. Greenhouse Climate Control

Greenhouse climate control focuses on maintaining suitable temperature and humidity conditions for plant growth. Yu et al. [6] reviewed various prediction and control techniques, including physical models, neural networks, fuzzy logic and optimisation methods. Although advanced approaches can improve accuracy and energy efficiency, simpler rule-based methods are more suitable for low-cost prototype systems. Based on this study, the proposed system integrates sensor-driven climate monitoring and automated control, where temperature and humidity are continuously monitored to support actions such as ventilation under unfavourable conditions.

D. AI and Computer Vision for Disease Detection

Computer vision has become an important tool for detecting plant diseases and pests. Katsoulas et al. [7] developed an environmental data-based system for estimating fungal disease risk before visible symptoms become severe. Yu et al. [8], using machine learning and deep learning models reviewed image-based disease detection techniques and highlighted the effectiveness of RGB and advanced imaging methods. Other studies [9], [10] demonstrate that plant images can be processed using lightweight or cloud-based models for disease classification.

Together, these works support the use of camera-based monitoring and image analysis for early disease detection in greenhouse environments. Based on these papers, we have integrated camera-based plant monitoring and image-based disease detection into the proposed system. This allows to extend the system beyond conventional environment sensing and incorporates direct observation of plant health as part of the overall greenhouse monitoring and management framework.

E. AI Explainability and Decision Support

Naagarajan and Streif [11] emphasizes the importance of making automated greenhouse decisions understandable to users. Their work shows that when provided explanations about the control recommendations, the usage of intelligent management systems is improved. Hence, instead of displaying only the raw sensor data, analytical insights and meaningful recommendations can provide effective support in decision making. Based on this study, the proposed system integrates user-oriented insights, alerts and understandable recommendations, helping users interpret conditions.

F. Red/Blue LED and Supplemental Lighting

Supplemental lighting can compensate for insufficient natural light and improve plant growth under controlled conditions. Rampinelli et al. [12] developed a sensor-based red and blue lighting system that responds to changes in ambient illumination. Niu et al. [13] further demonstrated that using intelligent controls for adjusting the lighting conditions improve photosynthesis and reduce energy-related impacts. These studies confirm the potential of adaptive supplemental lighting but indicate that lighting strategies based on different stages of plant growth require further integrated investigation. Based on this study, we have integrated the concept of intelligent red-blue supplemental lighting into the proposed AgriSync system. The system is intended to use environmental and light-related information to determine when supplemental illumination is required and support the controlled operation of red and blue lighting in accordance with the plant-growth requirements.

G. Machine Learning-Based Crop Yield Prediction

Kulyal and Saxena [14] reviewed that crop yield can be predicted using application of Machine Learning (ML) and Deep Learning (DL) techniques using different agricultural datasets.



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Their study identified soil type, precipitation, temperature, humidity, and crop-related parameters as commonly used features for predicting crop yield. The review found that Random Forest, Support Vector Machine, Decision Tree, and Logistic Regression are frequently used ML techniques, while Deep Neural Networks (DNN) and Convolutional Neural Networks (CNN) are commonly applied DL methods. The authors emphasized that a single ML model can not be considered optimal for all crop-yield prediction tasks, as performance depends on the dataset, crop type, and selected features. Based on this study, the proposed system can use the data collected from the sensors as input features for machine learning based crop yield prediction which enables the system to provide data-driven insights for the crop growth.

H. Literature Synthesis and Research Gap

The reviewed studies demonstrate significant progress in greenhouse monitoring [1], [2], [3], predictive irrigation [4], [5], climate control [6], disease detection [7], [8], [9], [10], decision support [11], and supplemental lighting [12], [13], crop yield prediction [14]. However, most existing works address these functions individually or combine only a limited number of them. Monitoring, irrigation, disease detection and lighting are often implemented as separate systems, while some approaches depend heavily on continuous connectivity or computationally intensive processing. Therefore, there remains a need for a coordinated and affordable greenhouse management framework that integrates environmental monitoring, predictive irrigation, climate management, disease detection and adaptive lighting within a single control structure.

III. COMPARATIVE ANALYSIS OF SURVEYED SYSTEMS

Table 1. Comparative analysis of selected research works relevant to AgriSync

AgriSync – Comparative Analysis of Literature Survey					
Sr. No.	Paper Title (Year)	Summary	Advantages	Disdvantages / Limitations	Remark
1	IoT-Based Monitoring and Control for Optimized Plant Growth in Smart Greenhouses Using Soil and Hydroponic Systems (2025)	Proposes a fully autonomous, solar-powered greenhouse with ESP32, extensive sensors (soil, water, nutrients, environment) and fault detection (Isolation Forest). Data sent to cloud via MQTT/HTTP.	- Wide range of sensors - Solar-powered / off-grid - Fault detection for sensors & power - Web & mobile monitoring	- Not tested in real greenhouse - Uses simulated fault data - Depends on Wi-Fi / cloud - Small prototype only	Wide sensor suite (soil moisture, pH, EC, nutrients), solar-powered approach, fault detection idea, cloud/web & mobile monitoring concept.
2	Developing a New IoT Network Topology for Effective Greenhouse Monitoring and Control (2025)	Four-stage IoT architecture (sensor nodes → border router → processing hub → visualization). Uses Crossbow Iris Motes, UDP radio link, Contiki OS, InfluxDB, Grafana dashboard.	- Scalable topology - Works with poor internet - Real-time + historical visualization - Low-power sensor nodes	- No automatic control loop - Limited sensors (Temp, Humidity, Light) - Extra devices increase cost - Mesh not implemented	4-block IoT architecture idea, edge processing hub concept, time-series data storage (InfluxDB), Grafana dashboard visualization.
3	A Web-Based System for Fungus Disease Risk Assessment in Greenhouses: System Development (2023)	Develops CNN-based model from leaf images to classify fungal diseases (6 classes, 220,000 images). Web system provides risk assessment.	- High accuracy (99.44%) - Large dataset - Web-based risk assessment - Early detection support	- Only fungal diseases - Needs good image quality - Limited to 6 disease classes - Dataset environment specific	AI/ML model for disease detection from leaf images, web-based risk assessment, early alert idea.
4	An IoT-Based Predictive Irrigation Scheduling Framework for Precision Soil Moisture Control in Greenhouses (2024)	Hybrid RF + XGBoost model predicts soil moisture for irrigation precisely. Achieves high accuracy with real greenhouse data.	- High prediction accuracy ($R^2=0.98$) - Saves water & energy - Hybrid RF + ML model - Real dataset validation	- Limited to soil moisture - Needs periodic retraining - Requires computational resources - Single greenhouse tested	AI-based soil moisture prediction for smart irrigation, hybrid ML model use, water & energy saving focus.
5	Enhancing Greenhouse Management with Interpretable AI (2025)	Uses SHAP + XGBoost to provide interpretable AI for disease detection, irrigation scheduling and climate control. Improves trust in AI decisions.	- Interpretable AI (transparent) - Multi-task (disease, irrigation, climate) - Improves trust & adoption - Better decision support	- Needs quality data - Computational complexity - SHAP adds processing overhead - Model performance varies with data	Interpretable AI (SHAP) for trustworthy decisions, multi-task AI (disease + irrigation + climate) for integrated control.
6	Simulink-Driven Digital Twin Implementation for Smart Greenhouse Environmental Control (2024)	Builds a digital twin of greenhouse in Simulink using energy balance model for real-time monitoring and control.	- Safe simulation of scenarios - Real-time monitoring - Better control tuning - Predictive insights	- Simulation vs real gap - Needs accurate parameters - Complex for small farms - High initial development	Digital twin concept for simulation & control testing, energy balance model for environmental control.
7	Prediction and Control of Greenhouse Temperature: Methods, Applications, and Future Directions (2022)	Comprehensive review of temperature prediction & control methods (fuzzy, ANN, MPC) and their applications.	- Detailed comparison of methods - Highlights future trends - Covers control strategies - Useful for system design	- Review paper (no implementation) - Some methods complex/costly - Not focused on small-scale setups	Different temperature control methods (fuzzy, ANN, MPC) knowledge for choosing best approach.
8	Advances in Computer Vision-Based Detection and Management of Greenhouse Pests and Diseases (2024)	Reviews CV techniques for detecting pests and diseases (CNN, YOLO, etc.) and management strategies.	- Covers latest CV models - Wide range of pests & diseases - Helps choose best approach - Improves detection systems	- Many models need large datasets - High computation for some models - Background variation issues	CV models (CNN, YOLO) for pest & disease detection, image dataset importance, real-time detection idea.
9	Intelligent Red-Blue Supplementary Lighting Control System for Greenhouses Balancing Photosynthesis and Carbon Footprint (2024)	RL-based lighting control adjusts red/blue LED ratio to improve photosynthesis while reducing carbon footprint.	- Reinforcement learning - Improves photosynthesis - Energy & carbon optimized - Real-time adjustment	- Needs training time - Requires accurate light sensors - Complex algorithm - Power cost of LEDs	Red/Blue LED spectrum control using AI, energy-efficient lighting strategy for better growth & low carbon footprint.
10	Development of Artificial Lighting System for Light Supplementation in Smart Greenhouses with Agrivoltaic Systems (2023)	Develops agrivoltaic + LED system to supplement natural light and improve crop yield.	- Energy-efficient - Combines solar + lighting - Improves yield - Sustainable approach	- High initial setup cost - Needs space for panels - Weather dependent - Complex integration	LED + solar (agrivoltaic) system concept, sustainable lighting strategy for yield improvement.
11	IoT-Based Smart Greenhouse Environment Monitoring and Predictive Control System (2024)	ESP32-based IoT system with sensors for monitoring and ML for predictive control of actuators.	- Real-time monitoring - Predictive control - ESP32 based - Cloud integration	- Depends on internet - Limited dataset - Small-scale test - Security not detailed	ESP32 + IoT + ML for predictive control, cloud integration, real-time actuator control idea.
12	Machine Learning for Greenhouse Crop Yield Prediction: A Review (2023)	Reviews ML models (LR, RF, XGBoost, ANN) used for crop yield prediction.	- Many algorithms compared - Useful performance metrics - Identifies trends - Helps model selection	- Review paper only - Needs quality data - Models vary by crop - No real system	ML models for yield prediction (RF, XGBoost, ANN), performance comparison for selecting best model.
13	IoT-Based Greenhouse Monitoring and Automation System Using LoRaWAN (2023)	Implements LoRaWAN for long-range monitoring and automation in greenhouse.	- LoRaWAN long range - Low power - Good for remote areas - Reliable communication	- Needs LoRaWAN gateway - Limited data rate - Higher initial cost - Fewer local integrations	LoRaWAN for long-range, low-power communication (SX1278), reliable remote monitoring & automation.
14	Edge AI for Smart Greenhouse: Disease Detection and Resource Optimization (2024)	Uses edge AI on microcontrollers for disease detection and resource optimization without cloud dependency.	- Works offline - Lower latency - Saves bandwidth - Reduces cloud cost	- Limited processing power - Smaller models less accurate - Harder updates - Limited storage	Edge AI for offline disease detection, low-latency decisions, bandwidth saving for remote farm usage.

IV. PROPOSED BLOCK DIAGRAM

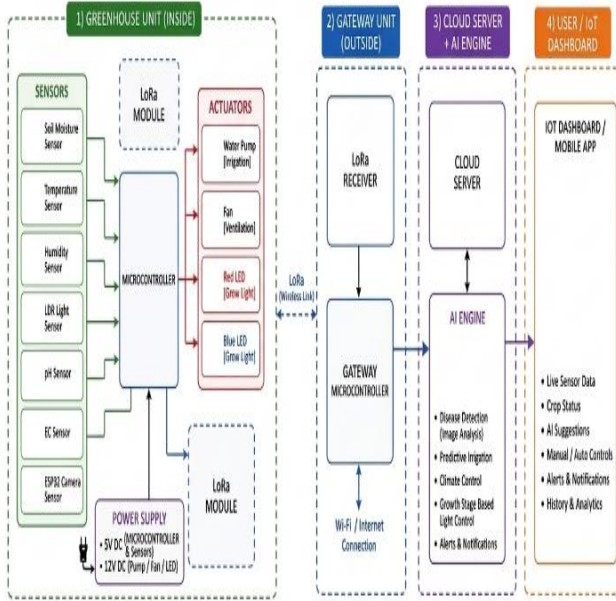


Fig. 1. Proposed Block Diagram

AgriSync is proposed as an integrated smart greenhouse monitoring and automation system designed to combine environmental monitoring, data communication, intelligent analysis and automated control within a coordinated framework. As illustrated in Fig. 1 and Fig. 2, the system consists of four functional blocks: the Greenhouse Unit, the Gateway Unit, the Cloud Server with an AI Engine, and the User/IoT Dashboard. The Greenhouse Unit forms the physical monitoring and control section. It collects information related to soil moisture, temperature, humidity, light intensity, pH and electrical conductivity, while plant images are captured for visual analysis. Based on received control decisions, the unit operates the irrigation pump, ventilation fan and red and blue supplemental lighting.

The collected sensor readings, device status and image information are transmitted from the greenhouse to the Gateway Unit through a wireless communication link. The Gateway Unit receives and forwards the information to the Cloud Server through an internet connection. The Cloud-based AI Engine processes environmental and plant data to support four main functions: disease detection from plant images, predictive irrigation scheduling, climate-control decisions and growth stage-based lighting recommendations. The generated recommendations or control commands are then returned through the Gateway Unit to the Greenhouse Unit, where the required actuators are operated.

V. PROPOSED FLOWCHART

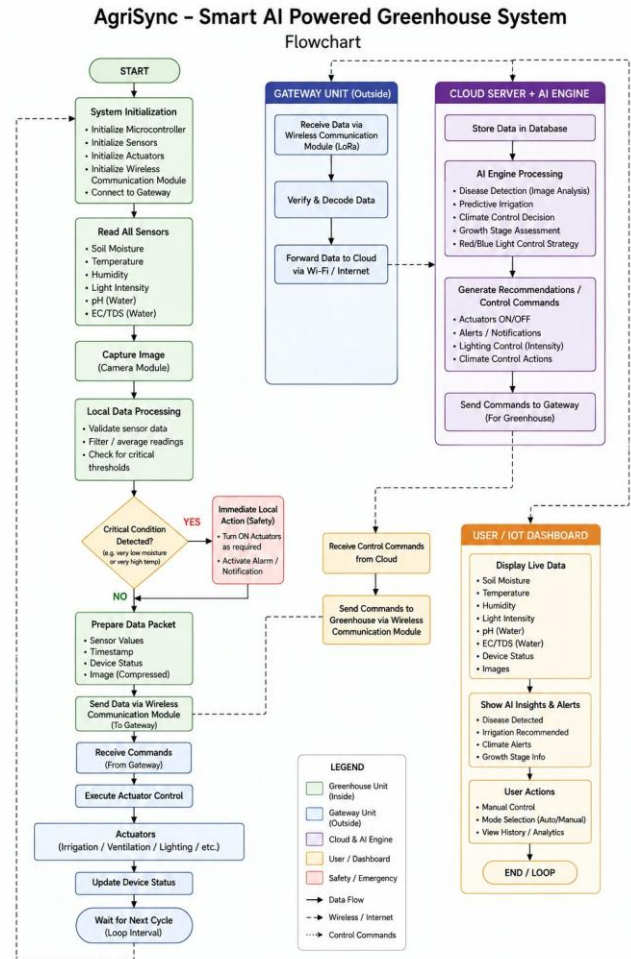


Fig. 2. Proposed Flowchart

In practical implementation, the system will function as a continuous monitoring and control cycle. After initialization, the sensors will collect real-time environmental data and the camera will capture plant images. The local controller will perform validation and will check for critical conditions requiring an immediate safety response, such as excessive temperature or very low soil moisture. The validated data will then be transmitted for further processing, and the resulting control decisions will be communicated back to the greenhouse. The dashboard will simultaneously provide the user with live readings, device status, plant images, alerts, analytical insights and manual or automatic control options.

REFERENCES

- [1] K. Bouarroudj, F. Babaa, and A. Touil, "IoT-Based Monitoring and Control for Optimized Plant Growth in Smart Greenhouses Using Soil and Hydroponic Systems," *Internet of Things*, 2025, doi: 10.1016/j.iot.2025.101710.
- [2] C. Dinn, R. Adhikari, E. Hassan, E. Shakshuki, and A. Eaman, "Developing a New IoT Network Topology for Effective Greenhouse Monitoring and Control," *Procedia Computer Science*, 2025, doi: 10.1016/j.procs.2025.07.183.
- [3] "IoT-Based Greenhouse Monitoring and Automation System Using LoRaWAN," 2023.
- [4] X. Ye, N. Shirakawa, K. Sano, and S. Zhang, "An IoT-Based Predictive Irrigation Scheduling Framework for Precision Soil Moisture Control in Greenhouses," *Agricultural Water Management*, 2026, doi: 10.1016/j.agwat.2026.110334.
- [5] "IoT-Based Smart Greenhouse Environment Monitoring and Predictive Control System," 2024.
- [6] J. Yu, C. Sun, J. Zhao, L. Ma, W. Zheng, Q. Xie, and X. Wei, "Prediction and Control of Greenhouse Temperature: Methods, Applications, and Future Directions," *Computers and Electronics in Agriculture*, vol. 237, art. no. 110603, 2025, doi: 10.1016/j.compag.2025.110603.
- [7] N. Katsoulas, D. Antoniadis, and A. Nikitas, "A Web-Based System for Fungus Disease Risk Assessment in Greenhouses: System Development," *Computers and Electronics in Agriculture*, vol. 188, art. no. 106326, 2021, doi: 10.1016/j.compag.2021.106326.
- [8] J. Yu, H. Wang, H. Cui, J. Liu, C. Sun, L. Guo, J. Wang, W. Zhang, and X. Wei, "Advances in Computer Vision-Based Detection and Management of Greenhouse Pests and Diseases: A Review," *Agriculture Communications*, vol. 4, art. no. 100146, 2026, doi: 10.1016/j.agcom.2026.100146.
- [9] J. Arshad, C. A. A. Sheheryar, M. K. I. Rahmani, A. Qayyum, R. Nasir, S. T. Chauhdary, and K. J. Almalki, "Simulink-Driven Digital Twin Implementation for Smart Greenhouse Environmental Control," *Egyptian Informatics Journal*, 2025, doi: 10.1016/j.eij.2025.100679.
- [10] "Edge AI for Smart Greenhouse: Disease Detection and Resource Optimization," 2024.
- [11] R. A. Naagarajan and S. Streif, "Enhancing Greenhouse Management with Interpretable AI: A Natural Language Interface for Advanced and Optimization-Based Control," *Smart Agricultural Technology*, 2025, doi: 10.1016/j.atech.2025.101041.
- [12] G. A. Rampinelli, R. Marcelino, J. P. Damasceno, C. C. Stalter, A. T. R. Bouchardet, G. Mohr, and V. Guber, "Development of Artificial Lighting System for Light Supplementation in Smart Greenhouses with Agrivoltaic Systems," *Renewable Energy*, vol. 231, art. no. 120914, 2024, doi: 10.1016/j.renene.2024.120914.
- [13] Y. Niu, L. Zheng, Y. Chang, Y. Zhang, Y. Li, Y. Han, H. Li, J. Cheng, S. Xiong, and M. Zhang, "Intelligent Red-Blue Supplemental Lighting Control System for Greenhouses: Balancing Photosynthesis and Carbon Footprint," *Computers and Electronics in Agriculture*, vol. 254, art. no. 112229, 2026, doi: 10.1016/j.compag.2026.112229.
- [14] "Machine Learning for Greenhouse Crop Yield Prediction: A Review," 2023.