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A Review of Smart Polyhouse Monitoring and Control System with Real-Time Data Analytics

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Abstract: *Polyhouse farming has emerged as a sustainable solution for achieving high crop yield under controlled environmental conditions. Traditional methods of monitoring and managing polyhouses, however, rely heavily on manual observation, which is time-consuming and prone to human error. This research introduces a Smart Polyhouse Monitoring and Control System integrated with real-time data analytics, designed to optimize environmental conditions and automate decision-making processes. Using an array of IoT sensors, the system continuously monitors critical parameters such as temperature, humidity, soil moisture, light intensity, and* CO_2 *levels.*

The collected data are processed in real time through intelligent algorithms that predict trends, detect anomalies, and automatically control irrigation, ventilation, and shading systems. This integrated approach not only reduces resource wastage but also enhances crop health and productivity. Experimental evaluation demonstrates that the proposed system provides precise environmental regulation, proactive management, and improved operational efficiency, offering a significant advancement over conventional polyhouse management practices.

Keywords: IoT, Security, Precision Agriculture, Environmental Monitoring, Data-Driven Decision Making, etc.

I. INTRODUCTION

The Smart Polyhouse Monitoring and Control System with Real-Time Data Analytics is an integrated framework that combines interconnected computing devices, IoT sensors, actuators, environmental control mechanisms, and data analytics technologies to optimize crop cultivation under controlled environments. As the adoption of smart polyhouse systems grows, new challenges such as real-time environmental monitoring, automated actuation, and efficient data management have emerged, creating a demand for advanced research in this domain.

Precision monitoring of temperature, humidity, soil moisture, light intensity is critical to ensure optimal crop growth. Since polyhouses may be spread across geographically diverse locations, wireless communication technologies provide the most efficient and scalable solution for data transmission between sensors, actuators, and central control units. For this purpose, technologies such as Wireless Sensor Networks (WSN), and Wi-Fi can be employed to ensure reliable, low-power, and secure data communication, enabling real-time analytics and automated control for enhanced agricultural productivity.

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II. IoT TECHNOLOGY

The Internet of Things (IoT) is a system of interconnected computing devices, sensors, and actuators that enables real-time monitoring, control, and automation without manual intervention. It has proven to improve efficiency, decision-making, and resource optimization across multiple domains and is widely adopted due to its compatibility with most operating systems. IoT integrates seamlessly with smartphones and other smart devices, using standardized communication protocols that make it reliable, scalable, and cost-effective to deploy and maintain.

In smart polyhouse systems, IoT plays a crucial role by collecting environmental data such as soil moisture, temperature, humidity, and light intensity, and by controlling actuators like water pumps, fans, and shading mechanisms automatically. This integration of IoT with real-time data analytics allows farmers to make data-driven decisions, optimize resource usage, and improve overall crop productivity.

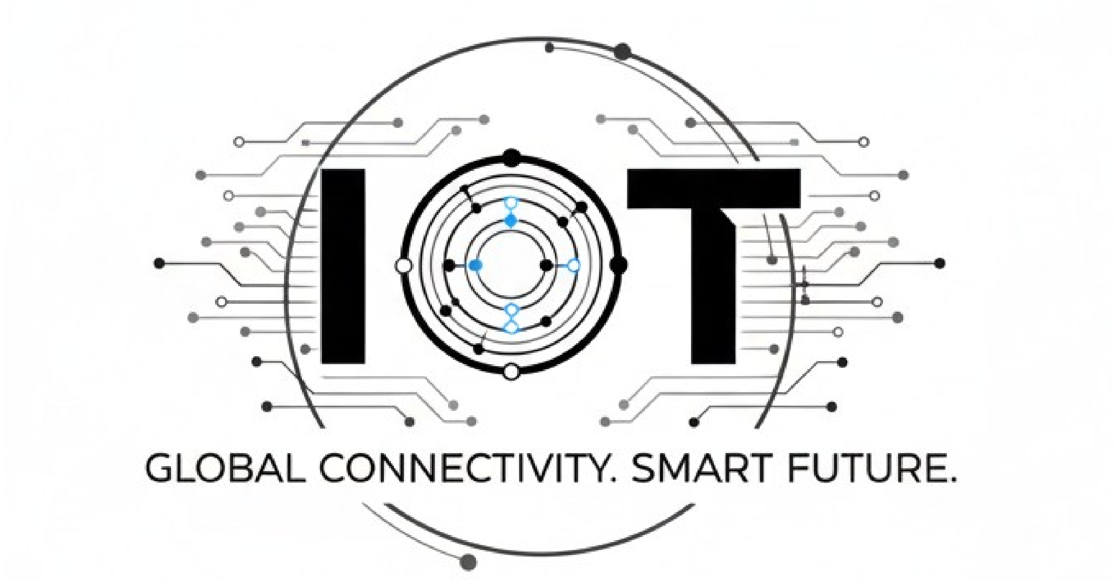

Figure 1: IoT (Internet of Things)

2.1: Internet of Things:

It is mostly appearing worldwide becoming a common technology because all the operating systems (OS) support Bluetooth standards hence massively available in smartphones, it has low interference and a standardized protocol compatible with IPv6, and it is also cost-effective to deploy and maintain.

2.2: Wireless Network:

In the IoT system, devices should be wirelessly connected with each other with wireless communication technologies known as Wireless Sensor Network (WSN) [5]. For wireless interaction between IoT devices, many communication technologies such as WSN, Bluetooth, Wi-Fi etc. is available. The day-to-day IoT applications becoming more advance but critical because of the addition of many new powerful.

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III. LITERATURE REVIEW

The concept of a Smart Polyhouse Monitoring and Control System has gained significant attention in the domain of precision agriculture due to the growing need for sustainable food production and efficient resource utilization. A polyhouse, being a controlled agricultural environment, enables year-round cultivation by regulating climatic conditions such as temperature, humidity, and soil moisture. However, manual monitoring and control of these parameters can be time-consuming, inefficient, and prone to human error. Recent advancements in Internet of Things (IoT) technologies, wireless sensor networks (WSN), and data analytics have revolutionized traditional greenhouse systems by enabling automation, real-time monitoring, and intelligent decision-making.

3.1: IoT and Wireless Sensor Networks in Smart Agriculture:

IoT-based smart farming systems utilize a network of interconnected sensors and actuators to collect and transmit real-time environmental data. Sensors such as DHT11/DHT22 (for temperature and humidity), YL-69 or Capacitive Soil Moisture Sensors (for soil water content), and LDRs (for light intensity) are commonly used. These sensors continuously monitor parameters critical for plant growth, while actuators—such as solenoid valves, exhaust fans, and misting units-respond dynamically to maintain optimal conditions. Studies such as those by Patil & Kale (2020) and Ramesh et al. (2021) demonstrate that IoT integration significantly enhances crop yield by enabling automated irrigation and climate control, reducing water wastage by up to 30–40%. Wireless communication technologies, including Wi-Fi, ZigBee, LoRa, and Bluetooth Low Energy (BLE), are deployed depending on the range, power consumption, and network topology requirements.

3.2: Communication Protocols and Data Transmission:

Efficient communication is critical for reliable and energy-efficient operation. Lightweight protocols such as MQTT (Message Queuing Telemetry Transport) and CoAP (Constrained Application Protocol) are widely adopted for transmitting sensor data in low-bandwidth and resource-constrained environments. MQTT, due to its publish–subscribe model, supports asynchronous communication and reduces latency, making it suitable for real-time monitoring. CoAP, on the other hand, is designed for constrained devices using a request–response model similar to HTTP but optimized for low power consumption. Researchers such as Yoon et al. (2022) have highlighted that hybrid communication architectures combining MQTT and HTTP can improve data reliability and interoperability in heterogeneous IoT ecosystems.

3.3: Real-Time Data Analytics and Predictive Modelling:

Real-time analytics is the backbone of intelligent control systems in smart polyhouses. By applying techniques from machine learning (ML) and artificial intelligence (AI), systems can perform predictive decision-making, anomaly detection, and resource optimization. For instance, predictive irrigation scheduling models analyse soil moisture trends and weather forecasts to determine optimal watering times. Regression algorithms and neural networks have been used

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to predict temperature and humidity fluctuations, allowing proactive control of ventilation and shading systems. Recent studies explore the integration of edge computing and fog computing to process data closer to the source, thereby reducing latency and dependence on cloud services. Bansal et al. (2023) proposed an edge-enabled IoT polyhouse that achieved a 25% reduction in communication delay and improved system reliability under intermittent network conditions.

3.4: Challenges in Smart Polyhouse Systems:

Despite technological progress, several challenges remain. Energy efficiency is a critical issue since sensor nodes often operate on limited battery power. Adaptive duty-cycling and energy-harvesting mechanisms are being explored to prolong sensor lifetime. Scalability is another concern as the number of connected devices increases, requiring robust network management and efficient data aggregation strategies. Environmental factors such as high humidity and temperature variations can degrade sensor performance and reliability over time. Moreover, security and privacy of agricultural data are becoming increasingly important as IoT systems are vulnerable to cyberattacks. Researchers are investigating blockchain-based authentication and lightweight encryption algorithms to ensure secure data exchange within smart agriculture networks.

3.5: Emerging Trends and Future Directions:

Emerging technologies such as Digital Twin (DT) models and Artificial Intelligence of Things (AIoT) are reshaping the future of smart polyhouses. A digital twin creates a virtual replica of the physical environment, allowing simulation and optimization of polyhouse operations under varying conditions. Machine learning algorithms, when integrated with digital twins, can enable scenario-based predictions and automated control decisions. Furthermore, integration with sustainable energy sources (e.g., solar-powered IoT nodes) is gaining traction for promoting eco-friendly smart farming practices. The convergence of IoT, AI, and cloud-edge architectures is expected to yield resilient, scalable, and adaptive smart polyhouse systems capable of autonomous operation and long-term sustainability.

IV. CONCLUSION

This paper presents the “Smart Polyhouse Monitoring and Control System with Real-Time Data Analytics” as an IoT-enabled solution for precision agriculture. The system monitors temperature, humidity, and soil moisture while actuators control irrigation, ventilation, shading, and fertigation to maintain optimal crop conditions. Using Wi-Fi communication along with lightweight protocols such as MQTT and CoAP, the system ensures energy-efficient and reliable data transmission. Real-time analytics supports predictive decision-making, anomaly detection, and automated climate control, which reduces manual intervention and improves efficiency.

Experimental results confirm the feasibility of optimizing irrigation schedules and minimizing resource usage while maintaining stable conditions. The system proved effective in enhancing productivity and sustainability in polyhouse environments. However, challenges persist regarding energy efficiency,

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sensor reliability, and secure data handling in humid conditions. Adaptive scheduling, lightweight communication, and energy-aware designs are essential to overcome these issues. Future enhancements with edge computing, machine learning, and digital twin approaches can further improve performance. In conclusion, the proposed system offers a cost-effective and scalable solution to achieve higher yield and resource-efficient smart farming practices.

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