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Smart Greenhouses

Integrating Artificial Intelligence and IoT in Floriculture

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Smart greenhouse systems integrating artificial intelligence (AI) and the Internet of Things (IoT) are emerging as advanced tools for precision monitoring and control in protected agricultural production systems. IoT-based sensor networks continuously monitor key environmental parameters such as temperature, humidity, soil moisture, and other microclimatic factors, providing real-time data for decision-making in controlled-environment agriculture. The collected data are analysed using machine learning algorithms to support predictive modelling, classification, and intelligent decision-making for optimized crop management. AI-enabled greenhouse systems facilitate autonomous regulation of environmental conditions, improving resource-use efficiency, reducing manual intervention, and enhancing overall system performance. Recent advances in deep learning and computer vision have expanded applications to automated plant growth monitoring and post-harvest quality assessment, including vase-life prediction in ornamental flowers. In floriculture, these technologies improve growth regulation, flower quality, and production uniformity under protected cultivation. Overall, the integration of AI, IoT, and automation enhances energy efficiency, precision resource management, and the sustainability of smart greenhouse systems, making them a promising approach for precision floriculture.

Keywords: Artificial intelligence, Internet of Things, smart greenhouse, precision floriculture, machine learning, sensors, automation, protected cultivation.

Introduction

The floriculture industry has emerged as a high-value segment of global horticulture, driven by the increasing demand for high-quality flowers, year-round production, and efficient resource utilization. Protected cultivation systems, particularly greenhouses, play a vital role in achieving these goals by providing controlled environmental conditions that enhance plant growth, flowering, and post-harvest quality. However, conventional greenhouse management relies heavily on manual monitoring and empirical operator experience, often resulting in inefficient input use and variability in crop performance under changing environmental conditions.

Recent advancements in digital agriculture have enabled the integration of the Internet of Things (IoT), artificial intelligence (AI), machine learning (ML), and sensor-based automation into controlled-environment agriculture. IoT-based sensors continuously monitor temperature, humidity, soil moisture, and carbon dioxide levels, supporting precise environmental regulation and automated control strategies (Jawad et al., 2017; Kirci et al., 2022). Machine learning techniques process these data for predictive modelling, classification, and decision support in optimized greenhouse operations (Liakos et al., 2018; Chaudhary et al., 2025). AI further enhances greenhouse automation by optimizing irrigation, fertigation, ventilation, and shading systems, thereby improving resource-use efficiency and minimizing manual intervention (Maraveas, 2023; Riskiawan et al., 2024). Recent advances in deep learning and computer vision have expanded applications to plant growth monitoring, disease detection, and post-harvest quality evaluation, including vase-life prediction in ornamental flowers (Ham et al., 2025; Lykokanellos et al., 2025).

Despite these advancements, adoption of AI- and IoT-enabled smart greenhouse systems in floriculture remains limited due to high costs, lack of standardization, interoperability issues, and limited crop-specific models for ornamental plants (Orchi et al., 2026; Villagran et al., 2025). Moreover, most existing systems have focused on general horticultural crops rather than floriculture-specific production (Salybekova et al., 2024). Consequently, understanding recent advances in AI- and IoT-enabled smart greenhouse technologies is essential to improve the efficiency, sustainability, and commercialization of precision floriculture.

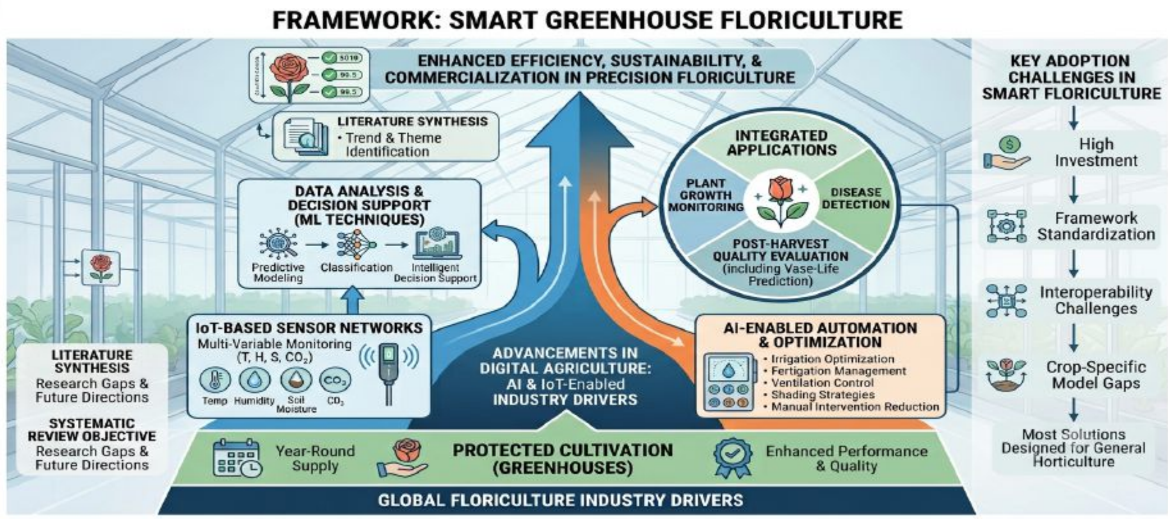

Figure 1. Conceptual framework of AI- and IoT-enabled smart greenhouse systems for precision floriculture.

Smart Greenhouse Architecture

A smart greenhouse is an advanced protected cultivation system that integrates the Internet of Things (IoT), communication networks, artificial intelligence (AI), machine learning (ML), and automated control systems to optimize plant growth and flower production. Unlike conventional greenhouses, it continuously monitors environmental conditions and automatically regulates cultivation practices to improve productivity, quality, and resource-use efficiency (Maraveas, 2023; Orchi et al., 2026).

Its architecture comprises four core components: IoT-based sensor networks, communication technologies, AI/ML-enabled data processing platforms, and automated control systems. IoT sensors continuously monitor key environmental parameters, including temperature, relative humidity, soil moisture, light intensity, and carbon dioxide concentration. Wireless communication technologies such as Wi-Fi, ZigBee, Bluetooth, and LoRa transmit real-time data to local or cloud-based platforms, where AI and ML algorithms analyse the collected data to support intelligent greenhouse management and automated decision-making (Kirci et al., 2022; Jawad et al., 2017; Liakos et al., 2018).

Based on the analysed data, automated control systems comprising actuators such as irrigation valves, fertigation units, ventilation fans, cooling systems, shading devices, and supplemental lighting automatically regulate the greenhouse environment with minimal human intervention (Maraveas, 2023; Riskiawan et al., 2024). This closed-loop workflow integrates real-time sensing, data transmission, AI-driven decision-making, and automated control to improve resource-use efficiency, reduce labour requirements, and support the sustainable production of high-quality ornamental crops (Ahmad et al., 2026; Orchi et al., 2026).

Table 1. Major components of a smart greenhouse architecture and their primary functions

Component	Major Function	Supporting references
IoT sensor network	Continuously monitors environmental parameters such as temperature, humidity, soil moisture, light intensity and CO_2 concentration.	Jawad et al. (2017); Kirci et al. (2022)
Communication technologies	Transfers real-time sensor data through wireless networks such as Wi-Fi, ZigBee, Bluetooth and LoRa for remote monitoring and control.	Jawad et al. (2017); Orchi et al. (2026)
AI/ML-enabled data processing platform	Analyses sensor data, predicts environmental changes and provides intelligent decision support for greenhouse management.	Liakos et al. (2018); Maraveas (2023); Orchi et al. (2026)
Automated control system (Actuators)	Automatically regulates irrigation, **fertigation**, ventilation, cooling, shading and supplemental lighting to maintain optimal growing conditions.	Maraveas (2023); Riskiawan et al. (2024)

Artificial Intelligence and Machine Learning Applications in Floriculture

Artificial intelligence (AI) and machine learning (ML) are revolutionizing greenhouse floriculture by enabling data-driven decision-making and automation throughout the crop production cycle. Unlike conventional systems that rely on manual observations, AI analyses data generated by IoT sensors to optimize greenhouse operations and enhance flower quality, productivity, and resource-use efficiency (Liakos et al., 2018; Maraveas, 2023).

One of the major applications of AI is intelligent climate management, where algorithms analyse environmental parameters such as temperature, humidity, light intensity, and carbon dioxide concentration to automatically regulate irrigation, fertigation, ventilation, shading, cooling, and supplemental lighting. This ensures optimum growing conditions while reducing water, fertilizer, and energy consumption (Riskiawan et al., 2024; Orchi et al., 2026).

Machine learning also enhances plant health monitoring through computer vision and deep learning, enabling early detection of nutrient deficiencies, pests, and diseases while supporting continuous assessment of plant growth for timely management decisions (Chaudhary et al., 2025; Maraveas, 2023; Kirci et al., 2022). In ornamental crops, AI technologies are increasingly used to improve cultivation practices and monitor plant performance under protected environments (Salybekova et al., 2024).

In floriculture, AI-powered imaging systems facilitate monitoring of flower development and post-harvest quality by predicting vase life, while AI-driven robotics automate crop monitoring and greenhouse operations, reducing labour requirements and improving operational efficiency (Ham et al., 2025; Lykokanellos et al., 2025).

Overall, integrating AI and ML with IoT-enabled smart greenhouse systems enhances environmental control, resource-use efficiency, crop health monitoring, and flower quality, supporting sustainable, efficient, and climate-resilient floriculture production (Ahmad et al., 2026; Salybekova et al., 2024).

Applications of AI and IoT in Precision Floriculture

1. Intelligent climate management: AI regulates temperature, humidity, light, and CO_2 to maintain optimum greenhouse conditions (Maraveas, 2023; Orchi et al., 2026).
2. Precision irrigation and fertigation: IoT sensors and AI optimize water and nutrient supply based on real-time crop needs, reducing wastage (Riskiawan et al., 2024; Orchi et al., 2026).
3. Plant health monitoring: Computer vision and deep learning enable early detection of nutrient deficiencies, pests, and diseases for timely management (Chaudhary et al., 2025; Maraveas, 2023).
4. Growth and flowering monitoring: AI continuously tracks plant growth, flowering stages, and environmental conditions for precision crop management (Kirci et al., 2022; Salybekova et al., 2024).
5. Post-harvest quality assessment: AI-based imaging evaluates flower quality and predicts vase life, improving storage and marketing of cut flowers (Ham et al., 2025).
6. Automation and robotics: AI-powered robots assist in greenhouse operations and crop monitoring, reducing labour and improving efficiency (Lykokanellos et al., 2025).
7. Remote monitoring: Cloud-based IoT platforms enable real-time greenhouse monitoring and data-driven decision-making from any location (Riskiawan et al., 2024; Orchi et al., 2026).

Challenges

- High initial installation and maintenance costs (Orchi et al., 2026).
- Limited digital infrastructure and internet connectivity in some regions (Villagran et al., 2025).
- Requirement for skilled personnel to operate AI- and IoT-based systems (Ahmad et al., 2026).
- Integration and interoperability issues among different sensors and devices (Maraveas, 2023).
- Cybersecurity and data privacy concerns in connected greenhouse systems (Riskiawan et al., 2024).
- Limited floriculture-specific datasets for training AI models (Salybekova et al., 2024).

Future Prospects

- Development of affordable smart greenhouse technologies for wider adoption (Ahmad et al., 2026).
- Integration of explainable AI for transparent and reliable decision-making (Orchi et al., 2026).
- Adoption of digital twins for real-time greenhouse simulation and management (Orchi et al., 2026).
- Increased use of AI-powered robotics for automated greenhouse operations (Lykokanellos et al., 2025).
- Integration of AI with smart LED lighting for precision crop management (Villagran et al., 2025).
- Expansion of climate-smart and sustainable floriculture through AI and IoT technologies (Ahmad et al., 2026).

Conclusion

Artificial intelligence (AI) and the Internet of Things (IoT) are transforming greenhouse floriculture by enabling precise monitoring, intelligent decision-making, and automated crop management. The integration of smart sensors, AI, and machine learning enhances resource-use efficiency, improves flower quality, reduces labour requirements, and supports sustainable protected cultivation. Despite challenges such as high investment costs, technical complexity, and limited floriculture-specific applications, continuous technological advancements are making smart greenhouse systems increasingly accessible and efficient. Wider adoption of these digital technologies will strengthen climate-resilient floriculture, improve productivity and profitability, and contribute to the sustainable growth of the ornamental horticulture sector.

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