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AI and Digital Monitoring in Floriculture Production

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Floriculture is a high-value and technology-intensive sector of horticulture that demands precise management of environmental, nutritional, and crop health parameters to achieve superior flower quality and market competitiveness. However, climate variability, increasing pest and disease pressure, labour shortages, inefficient resource use, and postharvest losses pose significant challenges to sustainable floriculture production. In this context, artificial intelligence (AI) and digital monitoring technologies have emerged as transformative tools for modern floriculture systems. The integration of AI with Internet of Things (IoT)-based sensors, machine learning algorithms, computer vision, robotics, unmanned aerial vehicles, and cloud-based decision support systems enables real-time monitoring, predictive analysis, and automation throughout the production and supply chain. AI-driven systems facilitate precision irrigation and fertigation, early detection of biotic and abiotic stresses, yield and quality forecasting, automated greenhouse climate control, and postharvest quality management. These technologies enhance resource-use efficiency, reduce production costs, improve flower uniformity, and minimise environmental impacts. Despite their immense potential, challenges such as high initial investment, data management issues, limited technical skills, and accessibility for smallholders restrict large-scale adoption. This review highlights recent advancements, applications, benefits, limitations, and prospects of AI and digital monitoring in floriculture production, emphasising their role in achieving sustainable, resilient, and economically viable ornamental crop systems.

Keywords: Artificial intelligence, Digital floriculture, Precision horticulture, Smart greenhouse, IoT sensors, Machine learning, Decision support systems, Sustainable floriculture

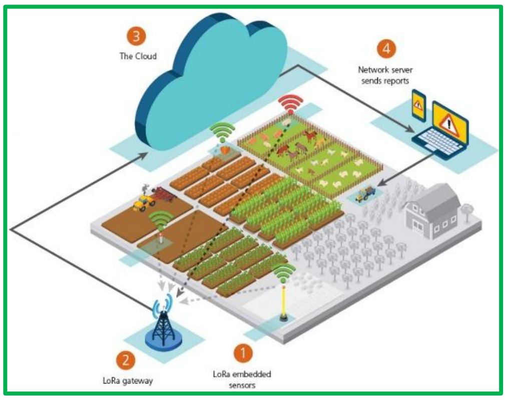
Introduction

Floriculture, encompassing the cultivation of cut flowers, potted plants, bedding plants, ornamentals, and landscape species, represents a high-value and technology-intensive segment of horticulture. The sector contributes substantially to farm income, employment generation, export earnings, and environmental aesthetics. However, modern floriculture faces multiple constraints including erratic climate conditions, increasing incidence of pests and diseases, rising labor costs, shrinking skilled workforce, inefficient input use, and substantial post-harvest losses. These challenges necessitate a paradigm shift from conventional management practices toward knowledge- and data-driven production systems (Sumalatha *et al.*, 2024).

Artificial Intelligence (AI) and digital monitoring technologies have emerged as transformative tools capable of addressing these limitations. Integration of AI with Internet of Things (IoT) devices, smart sensors, robotics, unmanned aerial vehicles (UAVs), cloud computing, and big data analytics enables real-time monitoring, predictive decision-making, and automation across the floriculture value chain. Digital floriculture supports precision input management, early stress detection, yield forecasting, quality enhancement, and sustainability, thereby improving both profitability and resilience of production systems.

Fundamentals of AI and Digital Monitoring in Floriculture

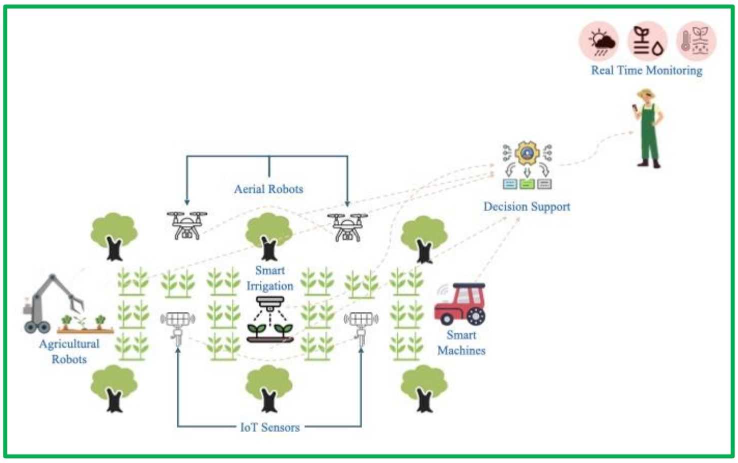
Artificial Intelligence in Horticulture



Artificial Intelligence refers to computational systems capable of mimicking human cognitive functions such as learning, reasoning, perception, and problem-solving. In floriculture, AI algorithms analyze large volumes of heterogeneous data generated from sensors, images, and historical records to generate actionable insights. Machine learning (ML) techniques such as regression models, support vector machines, random forests, and artificial neural networks enable pattern recognition and prediction, while deep learning (DL) architectures, including convolutional neural networks (CNNs), are particularly effective for image-based applications such as disease diagnosis and phenotyping Chaudhary *et al*., 2025.

Digital Monitoring Technologies

Digital monitoring involves continuous or periodic acquisition of crop, soil, and environmental data using electronic and optical devices. IoT-based sensor networks measure temperature, relative humidity, light intensity, CO_2 concentration, soil moisture, electrical conductivity, and nutrient status. Remote sensing platforms including drones and fixed cameras provide spatial and temporal information on crop growth and health. Cloud-based platforms integrate these datasets and support real-time visualization, alerts, and automated control decisions Kirci *et al*., 2022.



Objectives of Digital Monitoring in Floriculture

The primary objectives include optimization of microclimate conditions, efficient use of water and nutrients, reduction of chemical inputs, early detection of biotic and abiotic stresses, standardization of flower quality, and synchronization of production with market demand. Collectively, these goals align with the principles of precision horticulture and sustainable intensification Bhardwaj *et al*., 2024.

AI and Digital Monitoring in Floriculture

Study/System	Location	Technology Used	Outcomes
AI greenhouse monitoring	Netherlands	IoT + AI sensors	Reduced disease losses by 18%
Aeroponic greenhouse system	Experimental	DL + IoT	92% stress detection accuracy
Smart irrigation of roses	Field trial	ML + sensor data	Crop yield increase (reported)

AI-Enabled Monitoring and Control Systems

Smart Greenhouse Systems

Smart greenhouses represent one of the most advanced applications of AI in floriculture. These systems integrate sensor networks, AI-based controllers, and actuators to maintain optimal growth conditions automatically. AI algorithms continuously analyze environmental data and dynamically regulate heating, cooling, ventilation, shading, misting, fertigation, and supplemental lighting. Such closed-loop control systems minimize human intervention while ensuring uniform crop growth, improved flower size, color intensity, and extended vase life Salybekova *et al*., 2024.

Predictive models are increasingly used to anticipate environmental fluctuations and plant responses, enabling proactive management rather than reactive control. Studies in rose, chrysanthemum, gerbera, and carnation production systems have demonstrated improved resource-use efficiency and reduced disease incidence under AI-managed greenhouse conditions.

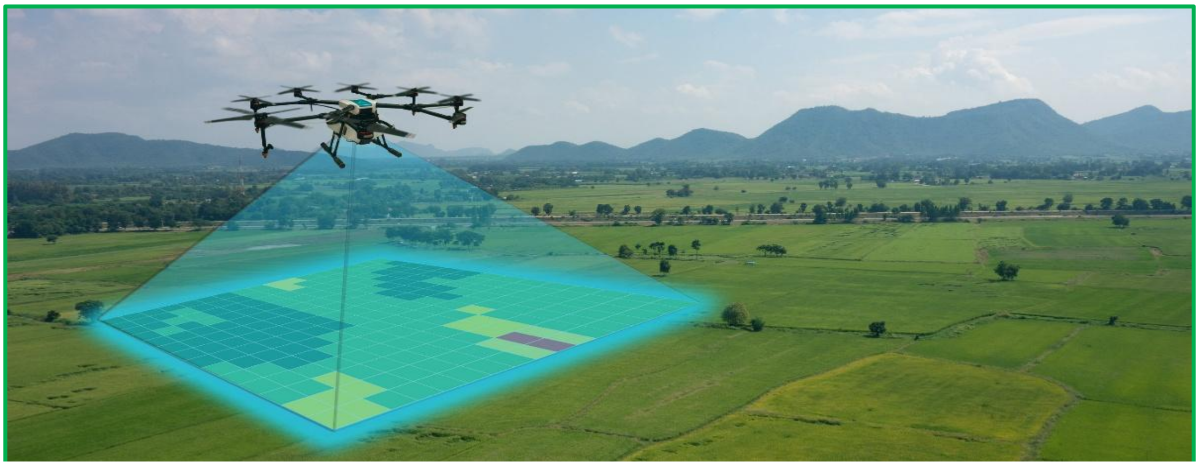
Environmental and Plant Health Monitoring

AI-based monitoring systems are capable of detecting subtle physiological changes in plants before visual symptoms appear. Computer vision systems analyze high-resolution images to identify early signs of fungal, bacterial, and viral diseases, as well as pest infestations. Deep learning models trained on annotated datasets can achieve high classification accuracy, supporting rapid and non-destructive diagnostics.

Sensor-driven stress detection models assess plant responses to drought, salinity, nutrient imbalances, and temperature extremes. Integration of multispectral and thermal imaging further enhances detection of water stress and canopy temperature variations, allowing timely corrective measures.

Robotics and Automation in Floriculture

Robotics plays an increasingly important role in addressing labor shortages and improving operational efficiency. AI-guided robots are employed for planting, transplanting, pruning, harvesting, grading, and packaging of flowers. Vision-guided robotic arms enable selective harvesting based on flower maturity and quality attributes, reducing mechanical damage and post-harvest losses.



Automated grading and sorting systems use image processing algorithms to classify flowers based on size, color, stem length, and uniformity, ensuring consistent quality standards for domestic and export markets. The adoption of robotics contributes to improved worker safety, reduced drudgery, and enhanced productivity Narimani *et al*., 2021.

AI-Based Decision Support Systems

Decision support systems (DSS) powered by AI integrate multi-source data to assist growers in strategic and tactical decision-making. Yield prediction models estimate flower output and harvest timing based on growth trends, environmental conditions, and historical performance. Such forecasts enable efficient labor planning, input procurement, and market scheduling.

AI-driven DSS also support pest and disease risk assessment, nutrient management recommendations, and economic optimization. By translating complex datasets into user-friendly insights, these systems empower growers to make informed, timely decisions Karumanchi *et al*., 2025.

AI Technologies and Applications in Floriculture

Technology	Description	Primary Application
Machine Learning	Predictive models	Yield & stress prediction
Deep Learning	Image classification	Disease detection
IoT sensors	Real-time monitoring	Environment/irrigation control
Robotics	Automation	Harvesting & grading

Precision Irrigation and Resource Optimization

Water management is critical in floriculture due to the sensitivity of ornamental crops to moisture stress. IoT-based soil and substrate sensors provide real-time information on water availability, while AI controllers determine optimal irrigation timing and volume. Precision irrigation systems reduce water consumption, prevent nutrient leaching, and improve root health. Advanced systems integrate plant-based sensors and image analysis to assess transpiration rates and canopy vigor, enabling truly demand-driven irrigation. Similar approaches are applied to fertigation, optimizing nutrient supply and minimizing environmental pollution Salvini *et al*., 2022.

Advanced Sensing and Remote Monitoring

Unmanned aerial vehicles equipped with RGB, multispectral, and thermal cameras offer rapid assessment of large-scale outdoor floriculture and landscape plantings. These platforms generate spatial maps of crop vigor, stress distribution, and growth variability. Although more commonly used in agronomic crops, UAV-based monitoring is gaining relevance in commercial floriculture, nurseries, and landscape management. Ground-based imaging systems complement aerial data by providing continuous, high-frequency monitoring within greenhouses and shade houses Amir *et al*., 2024.

AI in Post-Harvest Management and Supply Chains

Post-harvest losses remain a major concern in floriculture due to the perishable nature of flowers. AI applications in post-harvest management include prediction of vase life, optimization of cold storage conditions, and real-time monitoring of temperature and humidity during transportation. Machine learning models help in forecasting shelf life and identifying optimal logistics routes, thereby reducing wastage and maintaining quality.

Integration of AI with blockchain technology enhances traceability, transparency, and compliance with international quality standards, particularly for export-oriented floriculture industries Prakash *et al*., 2025.

Benefits and Impact of AI and Digital Monitoring

The adoption of AI and digital monitoring technologies results in increased productivity, improved quality consistency, reduced input costs, enhanced environmental sustainability, and greater resilience to climatic variability. These technologies also support data-driven research, innovation, and policy formulation in floriculture.

Challenges and Constraints

Despite significant potential, widespread adoption of AI in floriculture is constrained by high initial investment costs, limited digital infrastructure, data interoperability issues, lack of standardized datasets, and insufficient technical expertise among growers. Small and marginal producers face additional barriers related to affordability and access to technology.

Future Prospects and Research Needs

Future developments are expected to focus on low-cost sensor solutions, cloud-based AI platforms, integration of genomics and phenomics, autonomous robotic systems, and smart decision-support tools tailored for smallholders. Policy support, capacity building, and public-private partnerships will be crucial for scaling digital floriculture Singh *et al.*, 2025.

Conclusion

AI and digital monitoring technologies are reshaping floriculture production systems by enabling precision, automation, and sustainability. Continued research, technological innovation, and inclusive dissemination strategies will be essential to fully realize their potential in enhancing productivity, profitability, and environmental stewardship in the floriculture sector.

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