Agri Articles
(e-Magazine for Agricultural Articles)
Volume: 06, Issue: 04 (JULY-AUG, 2026)
Available online at http://www.agriarticles.com

Precision Floriculture: Integration of IoT, Sensors and Artificial Intelligence for Sustainable and Smart Ornamental Crop Production

*Sudhir Kumar Pathak
Agriculture Co-Ordinator, Buxar, Dept. of Agriculture, Govt. of Bihar
*Corresponding Author's email: sudhirpathak38@yahoo.com

Floriculture is an important branch of horticulture that focuses on the cultivation of flowers and ornamental plants for domestic use, landscaping, commercial trade and export. Because flower crops are valued mainly for their appearance, freshness, symmetry and postharvest life, they require careful management at every stage of production. Even small changes in soil moisture, temperature, light, humidity or nutrient supply can influence the growth and market quality of flowers. For this reason, modern floriculture is gradually moving toward more precise, data-based and resource-efficient methods of cultivation.

Precision floriculture uses connected devices, sensors, monitoring systems and automated controls to observe crop and greenhouse conditions in real time. These tools help growers manage irrigation, climate, plant growth and crop health more efficiently. Sensors measure important factors such as soil moisture, air temperature, relative humidity, light intensity, carbon dioxide level and substrate condition. The information collected is used to guide decisions related to watering, fertilization, ventilation, shading, and disease prevention. This approach helps reduce waste, improve flower quality and support sustainable production.

This article examines how the convergence of the Internet of Things (IoT), environmental and plant-based sensing, and artificial intelligence (AI) is reshaping floricultural production, from greenhouse climate regulation to automated grading and disease forecasting. It discusses the sensing and connectivity infrastructure that underpins these systems, the analytical role played by machine learning and computer vision, representative applications across the production and post-harvest chain, the economic and operational logic that justifies investment in these technologies, the practical and technical barriers that continue to limit widespread adoption, and likely directions for future development. The central argument advanced here is that floriculture's dependence on cosmetic uniformity and precise market timing makes it a particularly favorable and currently underexploited, domain for the application of IoT and AI relative to other agricultural sectors.

Introduction

The cultivation of ornamental plants has historically relied on the accumulated tacit knowledge of growers, who adjust irrigation, temperature and light exposure based on visual inspection and years of accumulated experience with a particular site, cultivar and climate. This knowledge is real and valuable, but it is also difficult to transfer, slow to update in response to changing conditions and inherently limited by the physical and cognitive capacity of a single observer to monitor a large growing area continuously. While experience-based management has sustained a global floriculture industry worth tens of billions of dollars annually and supplied cut flowers, potted plants and nursery stock to markets worldwide, it leaves considerable room for inefficiency relative to what continuous, quantitative monitoring can achieve.

Ornamental crops present a particular combination of characteristics that distinguishes them from staple food crops and even from most vegetable production. Species such as roses, chrysanthemums, gerbera, carnations and orchids are sensitive to comparatively small deviations in temperature, humidity, light intensity and photoperiod, substrate moisture and nutrient availability and the physiological consequences of stress are frequently visible directly on the harvested product in ways that affect its market value. Commercial value in floriculture depends on visual uniformity, color fidelity, stem architecture and post-harvest longevity rather than simply on biomass or caloric yield, even minor and transient environmental excursions can translate directly and disproportionately into economic loss.

Floriculture is also unusually input-intensive relative to the value density of the crop. Greenhouse structures used for high-value ornamentals require continuous heating or cooling to maintain narrow temperature bands, frequently rely on supplemental lighting to extend photoperiod or boost daily light integral during low-light seasons and depend on precisely formulated fertigation regimes to sustain rapid, uniform growth. Producers therefore face continual pressure to reduce energy, water and fertilizer costs without compromising the visual quality on which their revenue depends. Compounding this, demand for many ornamental products is not distributed evenly across the year but concentrated around fixed calendar events such as Valentine's Day, Mother's Day and various regional and religious festivals, meaning that the timing of flowering carries as much economic significance as its quality.

Traditional flower production often depends on routine practices and visual observation. Growers usually irrigate, fertilize and protect crops based on experience and general schedules. Although this method may work in some situations, it does not always respond well to changing weather or microclimatic conditions inside protected structures. A fixed schedule may lead to overwatering, nutrient loss or delayed response to stress. This is where precision floriculture becomes useful. Precision floriculture is based on the idea that plants should receive exactly what they need, when they need it. Instead of treating the entire crop in the same way, it allows management to be adjusted according to actual environmental conditions and plant status. This improves resource use, reduces waste and helps maintain consistent flower quality. In the present era of rising input costs, labor shortage, and climate uncertainty, such an approach is becoming increasingly important. The concept is especially relevant in ornamental horticulture because flower production is highly sensitive to quality standards. A crop may look healthy at a glance, but small hidden stresses can reduce stem length, flower opening or vase life. Precision tools make it possible to detect those stresses earlier and manage them more carefully. For growers who depend on premium markets that level of control can make a meaningful difference.

Meaning of precision floriculture

Precision floriculture refers to the use of digital monitoring, sensing systems, and automated control methods for managing ornamental crops more accurately. The aim is to improve crop performance while reducing unnecessary use of water, fertilizer, energy and pesticides. It is especially suitable for high-value flowers where quality and uniformity matter more than sheer quantity.

In practical terms, precision floriculture may include soil moisture monitoring, climate regulation inside a greenhouse, light management, and image-based assessment of crop growth. It can also support timely spraying, fertigation, and harvesting. The method is not limited to advanced farms; it can also be adapted to nurseries, small greenhouse units and urban ornamental production systems.

One of the main strengths of precision floriculture is that it combines observation with action. Sensors provide information, and control systems use that information to guide management decisions. This makes flower production more responsive and less dependent on guesswork. In high-value crops, even a small improvement in moisture regulation or temperature management can improve flower size, color and uniformity.

Another useful feature is that precision floriculture can be scaled according to the needs of the grower. A small unit may begin with only moisture and temperature sensors, while a larger greenhouse may include light, humidity, nutrient and gas monitoring. This flexibility makes the approach practical across different production systems.

Table 1: Main applications of precision floriculture

Area	Function	Benefit
Irrigation management	Water applied based on crop need	Saves water and prevents stress
Fertigation	Nutrient supply adjusted through sensors	Better plant nutrition
Climate control	Temperature and humidity regulation	Improved crop quality
Light management	Monitoring and control of light exposure	Better flowering and growth
Disease monitoring	Early detection of symptoms	Reduced crop losses
Postharvest care	Storage and transport condition control	Longer vase life
Greenhouse automation	Automatic operation of equipment	Lower labor demand

Sensors and their role

Sensors are the backbone of precision floriculture because they collect the data needed for careful management. Each sensor measures a particular environmental or crop-related factor. Together, they provide a detailed picture of plant conditions and help growers make better decisions. Soil moisture sensors are widely used because water status strongly influences flower growth. If the medium becomes too dry, plants may wilt or produce smaller flowers. If it remains too wet, roots may suffer and disease risk may increase. Moisture sensors help maintains a balanced water supply.

Temperature sensors are equally important because most flower crops are sensitive to heat and cold stress. Relative humidity sensors help maintain a favorable greenhouse atmosphere and reduce fungal disease. Light sensors are used to monitor solar radiation and photoperiod, which influence flowering behavior and plant form. Carbon dioxide sensors are useful in enclosed environments where enrichment may improve growth.

Other useful sensors include electrical conductivity sensors, pH sensors, thermal sensors and imaging devices. Electrical conductivity helps monitor nutrient concentration in fertigation systems. pH sensors help maintain the proper chemical balance of the root medium. Thermal sensors can indicate water stress through changes in canopy temperature. Cameras can capture changes in leaf color, flower opening or disease symptoms. In ornamental production, these readings are especially valuable because stress may first appear as a small reduction in visual quality. A flower crop may still survive under suboptimal conditions, but the final product may lose market value. That is why continuous monitoring matters so much in floriculture.

Table 2: Common sensors used in floriculture

Sensor type	Main function	Use in floriculture
Soil moisture sensor	Measures water content in soil or substrate	Irrigation scheduling
Temperature sensor	Measures heat conditions	Climate management
Relative humidity sensor	Measures moisture in the air	Disease prevention and ventilation
Light sensor	Measures light intensity and duration	Photoperiod and shading control
CO_2 sensor	Measures carbon dioxide level	Controlled environment

		management
EC sensor	Measures nutrient concentration	Fertigation control
pH sensor	Measures acidity or alkalinity	Root medium management
Thermal sensor	Measures canopy temperature	Water stress detection
Camera system	Captures plant images	Growth monitoring and symptom detection

Sensing and Connectivity Infrastructure

Environmental Sensing

The foundation of any precision floriculture system is a layer of distributed sensors that continuously capture the state of the crop and its environment. Environmental monitoring typically begins with temperature and relative humidity sensors positioned at canopy height rather than at a single reference point near the greenhouse wall or roof, since greenhouse and polytunnel environments are rarely uniform: shading from structural elements, proximity to vents and airflow patterns from heating or cooling equipment can produce meaningful micro-climatic variation across even a single bay. Commercial operations increasingly deploy multiple such sensors distributed across a growing area precisely to capture this heterogeneity rather than assuming a single reading is representative of the whole structure.

These temperature and humidity sensors are commonly paired with photosynthetically active radiation sensors, which measure the portion of the light spectrum usable for photosynthesis and allow calculation of the daily light integral, a cumulative measure of light received over a day that correlates closely with growth rate and flowering response in many ornamental species. This measurement in turn informs decisions about when and how much supplemental lighting to apply, particularly during winter months or at high latitudes where natural daily light integral may fall well below what a given crop requires. Carbon dioxide sensors serve a related function, allowing enrichment systems in enclosed structures to maintain concentrations above ambient atmospheric levels during daylight hours, since photosynthesis in a sealed or lightly ventilated greenhouse can become carbon-limited even when light and temperature are otherwise favorable.

A further refinement that has become common in more sophisticated systems is the calculation of vapor pressure deficit, derived from paired temperature and humidity readings rather than measured directly. Vapor pressure deficit expresses the difference between the amount of moisture the air is holding and the amount it could hold at saturation, and it correlates more directly with the physiological demand placed on a plant's stomata and therefore with transpiration rate and water stress, than relative humidity does on its own. Many modern greenhouse control systems now use vapor pressure deficit rather than humidity as the primary variable for climate control decisions, on the grounds that it better reflects what the plant is actually experiencing.

Substrate and Plant-Level Sensing

Below ground or below the growing medium in soil-less system, capacitive or time-domain reflectometry probes monitor substrate moisture content continuously, while paired electrical conductivity sensors provide a proxy for nutrient salinity in the root zone. These readings are essential for fertigation systems that aim to deliver water and nutrients in proportion to actual plant demand and substrate condition rather than according to a fixed volumetric schedule set in advance and they are particularly important in soil-less and hydroponic ornamental production systems, such as those widely used for roses and gerbera, where the growing medium has little buffering capacity and can shift from adequately moist to stressfully dry within a short period.

A growing number of operations supplement these indirect, substrate-based measurements with more direct measures of plant water status. Sap flow sensors, typically based on heat-pulse or heat-balance methods, measure the rate of water movement through the stem directly, providing a real-time indicator of transpiration and water uptake. Load-cell-based systems, sometimes referred to as weighing lysimeters, infer whole-plant or wholebench water use by continuously measuring changes in the combined weight of the plant and its growing medium, since weight loss between irrigation events corresponds closely to water lost through transpiration and evaporation. These direct measures are more expensive and more complex to deploy than substrate probes but offer a more physiologically grounded signal for irrigation decisions.

Imaging and Machine Vision Sensing

Increasingly, imaging plays as important a role in precision floriculture as point-based environmental sensing. Standard RGB cameras mounted above or alongside crop rows are used to monitor canopy development, count flowers and track visible changes in plant architecture over time. Multispectral cameras extend this capability by capturing reflectance in specific wavelength bands beyond the visible spectrum, commonly in the red-edge and near-infrared regions, which are particularly sensitive to changes in chlorophyll content and internal leaf structure associated with early plant stress, often before any change is visible to the human eye. Hyperspectral imaging, which captures reflectance across dozens or hundreds of narrow contiguous wavelength bands, is used primarily in research settings at present due to its cost and the computational demands of processing the resulting data, but it offers still finer discrimination between stress types, nutrient deficiencies and early disease symptoms than multispectral imaging alone.

Thermal imaging provides a complementary channel of information, since canopy temperature is influenced strongly by transpiration rate: a well-watered, healthy canopy tends to be cooler than the surrounding air due to evaporative cooling through open stomata, while a water-stressed or diseased canopy, in which stomata have closed or vascular function has been compromised, tends to run warmer. This makes thermal imaging a useful tool for detecting water stress and certain vascular or root diseases at a stage well before visible wilting occurs. Vegetation indices such as the normalized difference vegetation index, calculated from multispectral imagery, provide a further, spatially continuous measure of plant vigor across an entire growing area rather than at the limited number of discrete points a point sensor network can practically cover, making imaging a natural complement to, rather than a replacement for, the point-sensor infrastructure described above.

Role of Artificial Intelligence in Modern Floriculture

Sensor data acquires practical value only once it is translated into decisions and this is the function increasingly performed by machine learning models operating alongside or in some cases substantially in place of direct human judgment. The specific techniques employed vary considerably depending on the task, and it is useful to consider them separately.

Predictive and Adaptive Climate Control

In greenhouse climate management, models such as long short-term memory networks which are a class of recurrent neural network well suited to sequential time-series data are trained on historical environmental and growth records to forecast how internal conditions will evolve over the coming hours given current readings and external weather forecasts. Rather than waiting for a temperature or humidity threshold to be crossed before triggering a response as conventional thermostatic control does, such models allow ventilation, heating or shading to be adjusted proactively in anticipation of a forecast excursion. Reinforcement learning approaches have attracted particular research interest in this context because they allow a control policy to be learned and refined against an explicit, quantifiable objective, typically a combination of energy cost and deviation from optimal growing conditions, rather than relying on fixed set points defined in advance by a grower or engineer. In simulation and in a number of pilot greenhouse deployments, such learned control policies have been shown to achieve comparable or improved climate stability relative to conventional rule-based control while consuming less energy, since they can learn to exploit.

Computer Vision for Growth Monitoring and Grading

Computer vision has become one of the most mature and commercially deployed applications of AI within floriculture, in large part because the underlying convolutional neural network architectures used for image classification and object detection are well established and increasingly accessible even to firms without deep in-house machine learning expertise. Models trained on greenhouse or packhouse imagery are used to identify growth stage, distinguishing bud, partial bloom, full bloom and senescence, which allows harvest to be timed more precisely across a large planting than manual scouting typically permits, since a vision system can in principle assess every plant rather than a sampled subset. The same underlying object-detection techniques support automated counting of buds or open flowers for yield estimation well before harvest, giving growers earlier and more accurate forecasts of expected output than manual counting allows.

At the post-harvest stage, vision systems are used for automated grading of stem length, flower head size, petal color and uniformity, and the presence of physical defects such as bent necks, bruising or insect damage, tasks that have traditionally depended on subjective and inconsistent manual inspection by packhouse staff. Because grading directly determines the price grade at which a stem is sold, even modest improvements in grading consistency can have a direct effect on realized revenue, and automated systems offer the additional advantage of applying an identical standard continuously across very large volumes, which human graders, working at speed over long shifts, may struggle to do.

A closely related application is the early detection of pest and disease symptoms from imagery. Subtle changes in leaf color, texture, spotting patterns or canopy temperature, captured through RGB, multispectral or thermal imaging can be identified by trained classification or anomaly-detection models before an outbreak becomes visually obvious to a human scout or spreads widely enough through a crop to cause significant loss. This is particularly valuable for fast-moving fungal pathogens and for pests such as thrips and spider mites, whose early-stage damage can be difficult to distinguish from normal leaf variation without close, repeated inspection that is impractical to perform manually across a large growing area.

Predictive Disease and Pest Risk Modeling

Beyond image-based detection of symptoms that have already appeared, a further class of models is used for predictive disease risk modeling, which aims to forecast periods of elevated outbreak risk before any symptoms are present at all. These models typically combine environmental sensor data, particularly humidity, temperature and leaf wetness duration, with historical records of past outbreaks and known pathogen biology to estimate the likelihood that conditions favorable to a given disease such as Botrytis cinerea under prolonged high humidity and moderate temperature, will occur over a coming period. This allows growers to intervene pre-emptively, whether through targeted ventilation to reduce humidity or through selective, risk-triggered fungicide application, rather than applying chemical treatments on a fixed calendar schedule irrespective of whether conditions actually warrant it. A comparable logic is increasingly applied to insect pest management, where models combine environmental data with counts from IoT-connected pheromone or sticky traps to forecast periods of elevated pest pressure and guide the timing of monitoring or intervention.

Irrigation and Nutrient Optimization

A parallel application of machine learning addresses irrigation and fertigation management. Models integrate substrate moisture and electrical conductivity readings, weather forecasts and information on crop growth stage and cultivar-specific water requirements to generate irrigation and nutrient dosing schedules calibrated to genuine, current plant demand rather than to a fixed volumetric schedule established without reference to real-time conditions. This reduces both the direct waste associated with over-irrigation and the quality losses associated with under-watering stress, which in ornamental crops frequently manifests as reduced stem length, altered flower size or shortened post-harvest vase life. In more advanced deployments, these models are extended to account for the interaction between irrigation and other environmental variables, adjusting fertigation in response to elevated vapor pressure deficit or forecast high-radiation periods during which plant water demand is expected to rise.

Flowering Time Prediction

Because ornamental production is frequently tied to specific, fixed market dates rather than to a flexible harvest window, models that predict time to flowering carry particular commercial significance within floriculture relative to many other crop categories. Such models typically combine accumulated light exposure, expressed as daily light integral summed over the growth cycle, with temperature history, often expressed as growing degree days, and cultivar-specific developmental parameters derived from controlled trials, to estimate the date on which a given planting will reach a target growth stage. This allows growers to adjust planting dates, or to apply forcing treatments such as supplemental lighting, temperature manipulation, or growth regulators, in order to align flowering with peak-demand periods such as major holidays, rather than discovering after the fact that a crop has flowered too early or too late to capture premium seasonal pricing.

Decision-Support Integration

In practice, the outputs of these various models, covering climate forecasting, growth-stage and quality assessment, disease and pest risk, irrigation guidance, and flowering-time prediction, are rarely presented to growers as separate, disconnected outputs. Instead, they are typically consolidated into a single decision-support dashboard that presents live sensor readings alongside model forecasts, recommended actions, and exception-based alerts flagging conditions or predictions that require attention. This integration is significant because it reflects a broader shift in the grower's role, from one centered on continuous manual monitoring and direct intervention toward a more supervisory form of exception-based management, in which routine decisions are handled automatically and human attention is reserved for situations the underlying models flag as anomalous or uncertain.

Challenges and practical limitations

Although precision floriculture has many advantages, it is not without challenges. The first challenge is cost. Sensors, controllers, data systems and maintenance may be expensive for small growers. The return on investment may be slow in some cases, especially if the technology is not used properly. The second challenge is technical training. Growers need to understand how to install, operate and interpret the system. Without proper knowledge, the data may not be used effectively. The third challenge is maintenance. Sensors can become less accurate over time and must be calibrated regularly. Another issue is connectivity. Some farming areas may not have reliable internet or stable power supply. This can disrupt real-time monitoring and control. In addition, if systems are not designed carefully, they may collect too much data without providing clear guidance. In such cases, the technology becomes complex without giving practical benefits. For this reason, precision floriculture should be introduced gradually and in a practical way. Simple systems that monitor a few key factors may be more useful than highly complicated arrangements that are difficult to maintain. The focus should always remain on solving real production problems. There is also a need to match the technology with the scale of operation. A large commercial greenhouse and a small nursery will not need the same setup. Systems should be designed so that they are affordable, easy to use, and relevant to the actual crop and local conditions.

Conclusion

Precision floriculture is an important step forward in modern flower production. By using sensors, connected systems, and automated controls, growers can manage ornamental crops more accurately and efficiently. This helps improve flower quality, reduce waste and support sustainable production. The approach is especially useful in greenhouse and protected cultivation systems, where precise control of environment and inputs is essential. Although there are challenges related to cost, training and maintenance, the long-term benefits are strong. As technology becomes more accessible, precision floriculture is likely to become an increasingly common part of ornamental crop management. For growers who want better quality, more efficient input use and improved control over production, it offers a practical and modern solution.

References

1. Chlingaryan, A., Sukkarieh, S., & Whelan, B. 2018. Machine learning approaches for crop yield prediction and nitrogen management. *Computers and Electronics in Agriculture*, **151**:61-69.
2. Gebbers, R. and Adamchuk, V. I. 2010. Precision agriculture and food security. *Science*, **327**(5967): 828-831.
3. Kamilaris, A., & Prenafeta-Boldú, F. X. (2018). Deep learning in agriculture: A survey. *Computers and Electronics in Agriculture*, **147**:70-90.
4. Khanna, A., and Kaur, S. 2019. Evolution of Internet of Things (IoT) and its significant impact in precision agriculture. *Computers and Electronics in Agriculture*, **157**:218-231.
5. Kim, Y., Evans, R. G., and Iversen, W. M. 2008. Remote sensing and control of an irrigation system using a distributed wireless sensor network. *IEEE Transactions on Instrumentation and Measurement*, **57(7):** 1379-1387.
6. Mohanty, S. P., Hughes, D. P., and Salathé, M. 2016. Using deep learning for image-based plant disease detection. *Frontiers in Plant Science*, **7**:1419.
7. Ray, P. P. 2017. Internet of Things for smart agriculture. *Journal of Ambient Intelligence and Smart Environments*, **9(4):** 395-420.
8. Russell, S., & Norvig, P. (2021). *Artificial Intelligence: A Modern Approach* (4th ed.).
9. Singh, A., Ganapathysubramanian, B., Singh, A. K., & Sarkar, S. 2016. Machine learning for high-throughput stress phenotyping in plants. *Trends in Plant Science*, **21**:110-124.
10. Wolfert, S., Ge, L., Verdouw, C. and Bogaardt, M. J. 2017. Big data in smart farming- A review. *Agricultural Systems*, **153**(6): 69-80.