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Application of Robotics in Smart Floriculture Greenhouses

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The floriculture industry, which involves growing decorative flowers and plants in protected areas, is slowly adopting automation and robotic solutions to deal with labor shortages, improve accuracy, and improve the quality of crops in greenhouses. This review of robotics' use in smart floriculture greenhouses looks at the main tasks (planting, monitoring, harvesting, sorting, and packaging), the technologies that make these tasks possible (sensing, vision, manipulators, mobile platforms, and end-effectors), how they fit into greenhouse systems (climate control, IoT, and data analytics), and the costs, systems integration, crop specificity, and flexibility that affect the industry. It summarizes recent progress, gives examples of greenhouse robotics in floriculture, looks at problems that still need to be solved, and makes predictions about future research and use in the industry.

Overview

The global floriculture industry has grown quickly in the last few years because there is more demand for high-quality, year-round production of decorative flowers and plants. Greenhouses protect crops from the weather, but they also require a lot of work that often requires specialized or semi-skilled workers, like planting, trimming, surveying, harvesting, sorting, and packing. Many floriculture companies also have trouble finding workers, rising labor costs, and quality that isn't always good. Robotics and automation could be a way to do this. A lot of research has been done on culinary crops like tomatoes, peppers, and strawberries in the fields of horticulture and greenhouse robotics. However, decorative floriculture is becoming more and more popular. For example, the paper "Role of Artificial Intelligence and Robotics in Floriculture: A Review" by Uppuleti Sai Prakash et al. looks at how AI and robots can be used to grow flowers. JournalJabb.com In the meantime, more in-depth studies of greenhouse robots, like Bagagiolo et al.'s "Greenhouse Robots: Ultimate Solutions to Improve...," give technical summaries that are useful for floriculture. The three main points of this paper are: (1) the main tasks that robots can do in floriculture greenhouses, (2) the technologies that make robotic systems possible, and (3) problems with integration and industry practices (system architecture, business models, scalability, and barriers). The paper talks about how robots are used in smart greenhouses for growing flowers. Finally, it talks about problems and possible solutions.

Key Robotic Application Tasks in Floriculture Greenhouses

In a smart floriculture greenhouse, robotics can assist or automate several task categories, summarised below.

Transplanting and planting

In some floriculture processes, seedlings or plugs must be moved into containers, pots, or beds at a very high rate. Robotic plug seedling transplanters and other robotic transplanting tools for gardening are where the idea came from. For instance, assessments of horticulture robotics indicate that an emerging application is robotic transplanters utilizing manipulators and plug feeders. (Source:) Robotic transplanting could save labor costs in greenhouses that grow cut-flower liners or pretty potted plants, but it is not very common in the floriculture literature.

Checking, keeping an eye on, and sensing the health of crops

Florists need their greenhouses to have high standards for color, stem straightness, bloom size, and overall appearance. Robotic platforms with built-in sensors (like vision cameras, multispectral sensors, and LiDAR) could patrol greenhouse rows to look for problems with plants, such as disease, insect damage, bloom count, stem length, and more. Monitoring is highlighted in greenhouse robotics research as an essential facilitating "support task." Robotic monitoring in floriculture helps with deciding when to trim and harvest and lets you find quality problems early.

Collecting, sorting, and packing

One of the hardest things to do in floriculture is to harvest (cutting stems and bunching flowers), then grade and package them for sale. Robotic harvesting is becoming more common for fragile plants, even though it is still more common for food crops. "Robots for Harvesting of Horticultural Crop: A Review" gives a good overview of harvesting robots. To keep the petals, stems, and leaves from getting hurt, floriculture needs to be handled with care. Robotic systems with the right grippers, conveyors, or mobile platforms, as well as vision-based bloom maturity detection, could make it easier to harvest cut flowers or nursery plants.

Making pollination and growing automatic

Cut-flower crops like chrysanthemums, roses, and orchids need careful care like pruning, de-spiding, tying, pollination (to make seeds), and other tasks. "Robotic Pollination in Greenhouse Farming: Current Innovations, Challenges and Future Prospects" looks at the use of robotic pollinators in greenhouse farming. (orientjchem.org) Robots can also be used to automate tasks like fertilization, spraying, tying, or training stems. This will save time and make everything more uniform.

Sorting, packing, and moving things around Inside the Facility

Another big cost is sorting and packing the flowers after they have been picked, which is done by stem length, bloom size, and color class. Horticulture is quickly using robots and automation for sorting and packing, such as robotic arms, conveyor systems, and machine vision. There isn't much research on floriculture specifically, but these jobs are included in the more general greenhouse-robotics evaluations (e.g., Bagagiolo et al.) as "secondary" robot operations. In a smart greenhouse, mobile manipulators, also called "cobots," could move harvested stems to packaging stations without needing people to do it.

Enabling Technologies for Smart Floriculture Greenhouse Robotics

Successful deployment of robotics in floriculture greenhouses relies on multiple enabling technologies. Key among these are sensing and perception, actuation and manipulators, navigation and mobility, system integration and data analytics.

Ways of Seeing and Understanding

Robotic platforms need to be able to tell the difference between plants, stems, and flowers in order to do jobs like harvesting. Modern systems often use RGB-D cameras, stereo vision, LiDAR, and multispectral imaging. For example, a study on the 3D posture estimation of tomato peduncle nodes—despite tomatoes being an edible crop—illustrates how the reliability of robotic harvesting is enhanced through the integration of deep learning and point-cloud processing. (arXiv) Even though these methods aren't only for flowers, they can be used on flowers to tell when they're ready to bloom, when their stems bend, and when

their petals are damaged. According to reviews, one of the main jobs that greenhouse robots do is perception, which is figuring out what crops are.

Grippers, end-effectors, and manipulators

Floriculture needs to be handled with care. Robotic manipulators need to be built with the right dexterity and soft or custom end-effectors to keep petals, leaves, or stems from getting hurt. Research on horticulture harvesting shows how hard it is to deal with things that are fragile, hard to see through, and change direction. (Source:) In evaluations of greenhouse robotics, the focus on gripping system design (crop gripper) is evident. Creating adaptive grab techniques, vacuum suction systems that are made for delicate flowers, and soft-robotic grippers will be very important.

Moving and Getting Around in a Greenhouse

Greenhouse conditions have some unique problems, such as narrow aisles, overhanging structures, changing light, dampness, and sometimes slippery surfaces. Researchers have looked into mobile robot platforms that are on wheels, on rails, or hanging from cables. The Bagagiolo assessment says that guided displacement systems (like rails and fixed tracks) are often used to avoid complete localization problems. In floriculture greenhouses, robotic platforms may use autonomous mobile robots that move between benches or overhead gantry systems for crops with long stems. Some experiments done in urban hydroponic settings talk about cable-driven robots and rail systems for vertical farming (Simpson et al.). (Frontiers)

Combining Climate Control, IoT, and Smart Greenhouse

Smart floriculture greenhouses combine robotics, IoT sensors, data analytics, and decision support systems. Based on sensor data (like plant health and environmental factors), robotics platforms may start changes to the weather or watering. For example, Uppuleti Sai Prakash et al. talk about how AI and robots can help with predicting yields and controlling temperature in flower growing. JournalJabb.com System integration, which combines robotics with monitoring and controlling greenhouses, is a key area of study in the field of greenhouse robotics.

Self-Determination, Data Analytics, and Machine Learning

For robots to be truly useful in floriculture greenhouses, they need to be able to make their own decisions about when to harvest, how to grade, and how to move things. Robotic actuation and machine-learning algorithms that use large datasets of plant growth, bloom timing, and quality grading back this up. General evaluations of robotic harvesting focus on vision and machine learning for detection and planning how to grasp things, even though there isn't much material that talks about floriculture specifically. (Source:) Systems that learn from real greenhouse operations could make it possible for robots to adapt their behavior in floriculture.

Integration into Smart Floriculture Greenhouse Practice

While individual robotic tasks and technologies show promise, practical integration into smart floriculture greenhouses requires system-level thinking: architectural design, workflow adaptation, economic considerations, scalability and human-robot collaboration.

Designing the Robotic Ecosystem and Workflow

Robotics should be developed as an integral part of the greenhouse process, encompassing the entire journey from seedling to final product, rather than in isolation. A well-planned robotic ecosystem in a floriculture greenhouse could include a mobile robot for moving seedlings, a monitoring robot for counting blooms and checking plant health, a harvesting robot for cutting flower stems that is linked to a wrapper/packing line, and a logistics robot or cobot that moves bundles to shipping or cold storage. The most important thing is to connect with data systems, packing machines, conveyor systems, and systems that control the temperature in greenhouses. The "Greenhouse Robots" evaluation says that most research is still in the prototype stage and that scalability and integration are still big problems.

Work and Economic Issues

Floriculture usually needs a lot of work, doesn't make much money, and has strict quality standards. Robotics saves labor and makes things more uniform and of higher quality, but

there are some problems. For example, it needs to be adapted to each crop, it costs a lot to set up and maintain, and it needs to be maintained. Automation might make sense in floriculture because each stem is worth a lot, but there aren't many options that are the same. The study "Role of AI and Robotics in Floriculture" identifies cost and infrastructure limitations as significant challenges. JournalJabb.com ROI, payback time, reliability, and the ability to handle different types of flowers (like orchids, lilies, and roses) are all important practical factors.

Flexibility and Adaptation for Different Crops

There are many types of floriculture crops, such as bedding plants, exotic flowers, potted plants, and cut flowers like roses, carnations, and chrysanthemums. Robots have to deal with plants that come in different sizes, shapes, bloom locations, stem stiffness, and packing styles. Many tests of greenhouse robotics show how specialized robotic systems are; many are made for a certain crop or job. Robotic solutions that are flexible and modular will be easier for floriculture to use than highly specialized, custom-made machines.

Safety and Working Together Between People and Robots

Because floriculture operations are very delicate and people have high standards for how things look, robots will often need to work with people (cobots) instead of completely replacing them. This is especially true during transitions. Safety, ease of reprogramming, and natural human-robot interaction are all important factors. Some greenhouse robotics research looks at how manipulators and people interact with each other. (Source:) When thinking about the greenhouse conditions, which include dampness, slick surfaces, and overhanging rails, safety and durability are very important.

Examples and Case Studies from the Industry

The extensive assessments of greenhouse robotics include harvesting robots, rail-mounted systems, transportable platforms, and more; however, comprehensive case studies in floriculture are still in the nascent stages of development. Sánchez-Molina et al. (2024) present a PRISMA-based scoping study of greenhouse robotics from the 1980s onward. ScienceDirect These studies often say that harvesting is the most advanced primary job. These teachings can be used in floriculture, such as cutting flowers, grading stems, and so on. The "Role of AI and Robotics in Floriculture" study includes a number of international case studies of quantum adoption. JournalJabb.com

Challenges & Barriers

Despite promising advances, there are significant challenges in applying robotics in smart floriculture greenhouses.

The Fragility and Changeability of Crops

Flowers are more fragile than many crops that can be eaten. Petals can bruise, stems can break, and aesthetic flaws are more important. Robots need to be able to deal with changes in the timing of blooms, the length of stems, and the types of packaging. There are a lot of robotic systems that have been made for fruits with tough skins, like apples and tomatoes. These systems might not work well with delicate blooms.

Greenhouses' Environmental Limitations

Greenhouses have some problems, like narrow aisles, humid conditions, slippery or wet floors, overhead supports, thick canopies, and changing lighting. It is harder for robots to move around and find their way in these environments than it is in outdoor or field settings. Robotic greenhouse reviews stress that navigation and guidance are very important support tasks.

Flexibility and Changing Crops

Floriculture businesses can change the variety of flowers they grow often (color, packaging, bloom size), which is different from orchards or long-term crops. Robotic systems need to be able to handle changes in product lines, be reconfigured, and still make money. A lot of the systems that are already in place are specialized and don't allow for changes.

Cost, Upkeep, and Growth

The cost of robotic systems (mobile platforms, manipulators, sensors, and integrative software) is high. It is harder to keep things in good shape in a greenhouse because of the humidity, chemicals, and high temperatures. It must be shown that high-value crops will give you a return on your investment. The "Greenhouse Robots" review says that most of the systems that have been reported are still prototypes and not widely used in business.

Integration, Data, and System Complexity

Using robots in a smart greenhouse means combining them with climate control, sensor networks, data analytics, the Internet of Things (IoT), and managing the workforce. It is hard to integrate robotics into whole systems, and many growers don't have the resources to do so. Also, there isn't as much data for machine-learning models in floriculture as there is for big edible crops.

Rules, Work, and Social Issues

Some of the practical issues are worker displacement, worker skills, change management, and safety rules (especially when mobile robots are near people). Also, in many countries, growing flowers takes a lot of work, so it's important for workers to be involved, trained, and open to using robots.

Future Research Directions and Industry Outlook

Looking ahead, the application of robotics in smart floriculture greenhouses can progress in several directions:

Flexible and modular robotic platforms for multivariate flowers

Making modular robotic systems that can handle different types of flowers, stem lengths, and bloom packing styles will help adoption. End-effectors that are easy to plug in and use, vision systems that learn from flower-specific datasets, and adaptive grippers will all be useful.

Putting together smart greenhouse ecosystems

Robots shouldn't work alone; they should be part of a smart greenhouse ecosystem that includes condition-based harvesting, cloud data analytics, IoT sensors, and predictive scheduling. By combining robots with crop modeling, disease detection, and climate monitoring, we will be able to run fully integrated operations.

Robots and people working together (cobots)

Cobots that assist human workers with delicate tasks such as pruning, picking, and preparation may be adopted more rapidly than those that entirely supplant humans. Floriculture will gain from investigations into wearable robotic assistive devices, secure collaborative work environments, and pragmatic human-robot interactions.

AI/ML for Flower-Specific Tasks

There is a lack of research on machine learning models trained on floriculture datasets, such as bud count, stem quality, and flower bloom detection. Perceptual systems made just for floriculture will add value. There is still research going on to find out how to tell if a stem is damaged, grade its quality, and predict how much it will yield.

Scalable and cost-effective systems for small and medium-sized growers

Many greenhouses for growing flowers are medium-sized, but big growers might be able to afford expensive robots. Cooperative adoption, leasing or renting models, retrofit options, and reasonably priced robotic modules could all help get the word out to more people.

Standards for Data and Benchmarking

As studies of greenhouse robots show, many systems are still in the prototype stage. To make them better, we need benchmark data, repeatable testing, and standardization of performance criteria like cycle time, accuracy, and damage rate. A benchmark dataset designed for floriculture would speed up research.

Putting the Circular Economy and Sustainability Together

Robotics should help with sustainable greenhouse operations, such as growing plants in a way that uses fewer resources (water, nutrients), reduces waste, and uses energy more

efficiently. Robots that can monitor things in real time might be able to use resources more efficiently and have less of an effect on the environment.

Conclusion

Floriculture greenhouses are still in the early stages, but they are moving toward smart, robotic-assisted operation. Robotics has a lot of benefits, such as lower labor costs, better quality, more consistency, easier data integration, and better temperature control. Mobile platforms, manipulators, and vision systems are being used to do important tasks like harvesting, sorting, and keeping an eye on things. These systems are based on technologies that make them possible, such as machine learning, IoT integration, mobile navigation, soft grippers, and better perception. To fully realize floriculture's potential, we need to overcome some challenges, such as the delicate nature and variety of flowers, greenhouse environmental restrictions, crop-type flexibility, cost and scalability, system integration complexity, and workforce/social aspects. In general, the future looks good because data analytics, robotics, and smart greenhouse control are coming together to make floriculture greenhouses where robots work together to make high-value ornamentals with higher throughput, less labor, better quality, and less harm to the environment. Creating modular robotic systems that are good for floriculture, making benchmarks and datasets, and doing real-world pilot tests will speed up the adoption of these systems by academics. Businesses will need to show that they are cost-effective, reliable, and adaptable.

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