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PLANTBOT: AI AND ROBOTICS FOR AUTOMATED FLORICULTURE

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ABSTRACT

Floriculture is undergoing a significant transformation with the integration of automation, artificial intelligence (AI), and Internet of Things (IoT) technologies to address rising global demand, labor shortages, and sustainability challenges. This paper presents *PlantBot*, a fully automated robotic nursery system designed to optimize the cultivation of high-value ornamental and edible plants in controlled environments. The system combines robotic arms, autonomous guided vehicles (AGVs), machine vision, IoT-based sensors, and cloud-based AI algorithms to automate the entire plant production cycle—from substrate preparation and sowing to harvesting and distribution. PlantBot enables real-time environmental monitoring, plant health diagnostics, and adaptive resource management, significantly increasing productivity, improving product consistency, and reducing labor costs and environmental impact. Through pilot implementation in a semi-industrial greenhouse, the system demonstrated its potential to revolutionize nursery operations and set a scalable model for future sustainable floriculture and edible plant production.

Keywords: floriculture; automation; artificial intelligence; internet of things; robotics; edible flowers

1. INTRODUCTION

Floriculture is a diverse and rapidly evolving sector encompassing the cultivation of cut flowers, loose flowers, ixoras, cut foliage, potted plants, dried flowers, and plants used for the extraction of aromatic oils and natural colorants. While loose flowers are predominantly grown in open fields, cut flowers are typically cultivated in controlled environments such as greenhouses. In 2023, the global cut flower market was valued at $30.9 billion and is projected to reach $52 billion by 2031, growing at a compound annual growth rate (CAGR) of 6.0%. Major importers include the United

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States, the United Kingdom, and Germany, as highlighted in recent market analyses (Shahaniya et al., 2025).

The convergence of floriculture and horticulture is becoming increasingly pronounced, particularly with the emergence of edible flowers as a novel food category—often referred to as the "new vegetable." These flowers are gaining popularity for their sensory appeal, aesthetic value, and nutraceutical benefits. This trend reflects growing consumer demand for innovative and health-enhancing food products (Benvenuti & Mazzoncini, 2021).

Historically, flowers have held symbolic and aesthetic significance in both cultural and culinary contexts. Their integration into modern cuisine is being revitalized through an emphasis on their sensory, nutritional, and historical culinary properties. This perspective has inspired chefs, food designers, and consumers to view edible flowers not only as ornamental garnishes but also as functional food ingredients. The increasing awareness among health-conscious consumers has led to heightened interest in edible vegetable flowers (EVFs), which are recognized for their diverse nutritional attributes and health-promoting potential (Kumar et al., 2025).

In recent years, the market for edible flowers has expanded substantially and is expected to continue growing. The aesthetic and sensory characteristics of flowers have significantly influenced their integration into gastronomy, contributing to their rising culinary demand (Rodrigues & Spence, 2023). Despite this market potential, the cultivation of edible flowers remains highly labor-intensive, posing a critical barrier to widespread adoption among growers (Taddei et al., 2024).

The precise cultivation of edible flowers, especially for high-end gastronomic use, demands continuous environmental monitoring and fine-tuned control over growing conditions. Sensor-based systems are increasingly used to automate greenhouse management, thereby enhancing efficiency and consistency in production (Sharma et al., 2024).

Floriculture is undergoing a transformative shift, propelled by the adoption of artificial intelligence (AI) and automation technologies. These innovations are essential in addressing sector-wide challenges such as climate change, resource constraints, and labor shortages. Emerging tools like smart irrigation, automated harvesting, and AI-powered disease detection are redefining production paradigms, enhancing sustainability, and improving product quality. This digital transition is becoming critical for maintaining competitiveness in the global floriculture industry (Santhoshini, 2025).

AI is playing a pivotal role in this transformation, offering tools to increase precision, reduce resource inputs, and optimize productivity. To meet the expanding global demand and to establish more sophisticated standards, AI integration into floriculture practices is not only beneficial but

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necessary (Farjana et al., 2024). By enabling data-driven decision-making, AI supports smart irrigation, nutrient optimization, environmental control, and early disease detection through sensor arrays and drones. The combination of AI and Internet of Things (IoT) technologies ensures stable, high-quality flower production while minimizing waste and manual labor—marking the advent of smart farming.

The integration of AI with robotics is revolutionizing traditional floriculture, introducing a high level of automation that enhances efficiency and consistency (Prakash et al., 2025). Robotic systems are now capable of executing complex tasks such as planting, transplanting, harvesting, and intra-facility transport with precision. These systems help reduce product damage, improve workflow, and lower dependency on manual labor. Smart greenhouses, managed by AI platforms, regulate key parameters such as temperature, humidity, irrigation, and lighting using sensors and automated systems, thereby optimizing plant growth while conserving natural resources. Furthermore, AI-driven logistics streamline the post-harvest process, including demand forecasting, sorting, and robotic packaging, ensuring timely delivery of high-quality flowers to the market. The integration of automation across the entire production chain—from nursery to distribution—is steering floriculture into a technologically advanced and environmentally sustainable era.

Despite the opportunities presented by this technological shift, modern nursery operations face persistent challenges. These include the need to enhance productivity, ensure uniformity and high product quality, control rising labor costs, and optimize resource use (Benos et al., 2020). Traditional nursery practices, heavily reliant on manual labor, are increasingly considered unsustainable. In response, there is growing momentum to adopt advanced, technology-driven approaches for nursery modernization (Grimstad & From, 2017).

Automation and robotic technologies present viable and scalable solutions to these challenges, with the potential to reshape the primary sector (Bechar & Vigneault, 2017). The convergence of robotics, AI, and machine vision facilitates the development of fully automated systems capable of executing complex cultivation tasks with accuracy and reliability. These systems contribute not only to increased productivity and labor reduction but also to environmental sustainability by optimizing the use of water, energy, and other inputs (Ofori et al., 2022).

The transition from manual to automated systems in plant production is motivated by both economic and operational imperatives. On one hand, growers seek higher productivity and consistent output quality; on the other, rising labor costs and workforce shortages have created urgency for automation. Robotics provides a timely solution by enabling fast, accurate execution of repetitive tasks such as substrate filling, sowing, transplanting, and plant handling (Bac et al.,

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2014). The integration of machine vision with robotic arms further enhances precision in plant identification, classification, and management.

AI and IoT technologies further expand the capabilities of robotic nursery systems (Shamshiri et al., 2018; Kamilaris & Prenafeta-Boldú, 2018). IoT-based sensors enable real-time data acquisition on environmental conditions and resource usage, while AI algorithms analyze this data to dynamically adjust parameters such as irrigation schedules, fertilizer dosing, and lighting regimes (Liopa-Tsakalidi et al., 2024). This synergy allows for highly responsive, adaptive cultivation environments.

While previous studies have explored the potential of robotic solutions for discrete tasks in nursery production—such as harvesting or planting (Grimstad & From, 2017; Tang et al., 2020)—few systems offer comprehensive automation across all stages. **PlantBot** distinguishes itself by delivering a fully integrated, end-to-end solution for automated nursery production. From substrate preparation to the final distribution of plants, PlantBot automates every critical step, supporting the cultivation of both ornamental and high-value edible plants.

This paper presents **PlantBot**, a fully automated robotic nursery system designed to meet the growing demand for premium floricultural and edible plants. The system seeks to overcome limitations of traditional methods by enhancing productivity, improving product consistency, reducing environmental impact, and advancing economic viability through autonomous operation. In doing so, PlantBot offers a scalable, innovative model for the future of sustainable plant production.

2. MATERIALS AND METHODS

2.1 System Overview

PlantBot is a fully automated robotic system designed to manage the production of high-value floricultural and edible plants within a controlled environment. It integrates advanced technologies that operate synergistically to optimize efficiency, precision, and consistency throughout all stages of the production process.

At the core of the system lies the integration of robotic components, machine vision, artificial intelligence (AI), an Internet of Things (IoT) sensor network, and a cloud computing platform. Robotic arms execute key tasks such as planting, transplanting, and handling plant material and substrates with high precision, while autonomous guided vehicles (AGVs) facilitate the internal transport of plant material across the production facility. Machine vision technologies enable real-time plant identification and quality assessment, supporting the accurate coordination of robotic operations. AI algorithms are employed for data analysis, plant health monitoring, predictive maintenance, and system-wide production optimization.

Concurrently, IoT sensors continuously monitor and transmit critical environmental variables—including temperature, humidity, and CO_2 concentration—as well as substrate-specific parameters such as moisture content, pH, and electrical conductivity. All data streams are consolidated within a cloud-based computing platform, enabling real-time system management, remote diagnostics, and data-driven decision-making.

The pilot implementation of PlantBot is being conducted at a greenhouse enterprise with extensive experience in floriculture and controlled-environment agriculture. The facility provides the necessary infrastructure for semi-industrial scale installation and evaluation. Stakeholders from both production and research sectors contribute by offering access to infrastructure, operational documentation, and performance data. This collaboration supports the systematic assessment of PlantBot's technological and operational effectiveness under real-world conditions and facilitates iterative system improvements aimed at developing a replicable, commercially scalable production model.

2.2 Process Flow

The automated production flow of PlantBot comprises nine sequential and interconnected stages designed to ensure holistic, precise, and optimized plant cultivation within a controlled environment. The process begins with the substrate intake and preparation phase, during which robotic units homogenize the substrate material and adjust its moisture content to optimal levels, establishing favorable conditions for germination and root development.

The second stage involves sowing and seedling preparation under fully controlled environmental conditions, which promote high germination rates and uniform seedling emergence. Once the seedlings reach an appropriate developmental stage, they are accurately transplanted into growth containers using robotic arms guided by machine vision systems, enabling gentle, targeted handling and minimizing mechanical stress.

Subsequently, autonomous guided vehicles (AGVs) transport the plants throughout the facility according to the specific requirements of the production schedule. Cultivation continues under continuous and dynamic environmental monitoring, with IoT sensors and AI algorithms jointly regulating key variables such as temperature, humidity, light intensity, and photoperiod to support optimal growth.

Plant health is assessed continuously using integrated cameras and sensors, with real-time data analysis performed by AI algorithms that enable early detection of physiological stress, nutrient deficiencies, or disease symptoms. Irrigation and nutrient delivery are automated and individually tailored, while LED-based lighting systems dynamically adjust intensity and spectral composition to enhance photosynthetic efficiency.

At maturity, robotic subsystems carry out the harvesting and initial packaging of the plants. The final stage involves storage and distribution, supported by an integrated Warehouse Management System (WMS) that ensures full traceability, inventory control, and efficient logistics management.

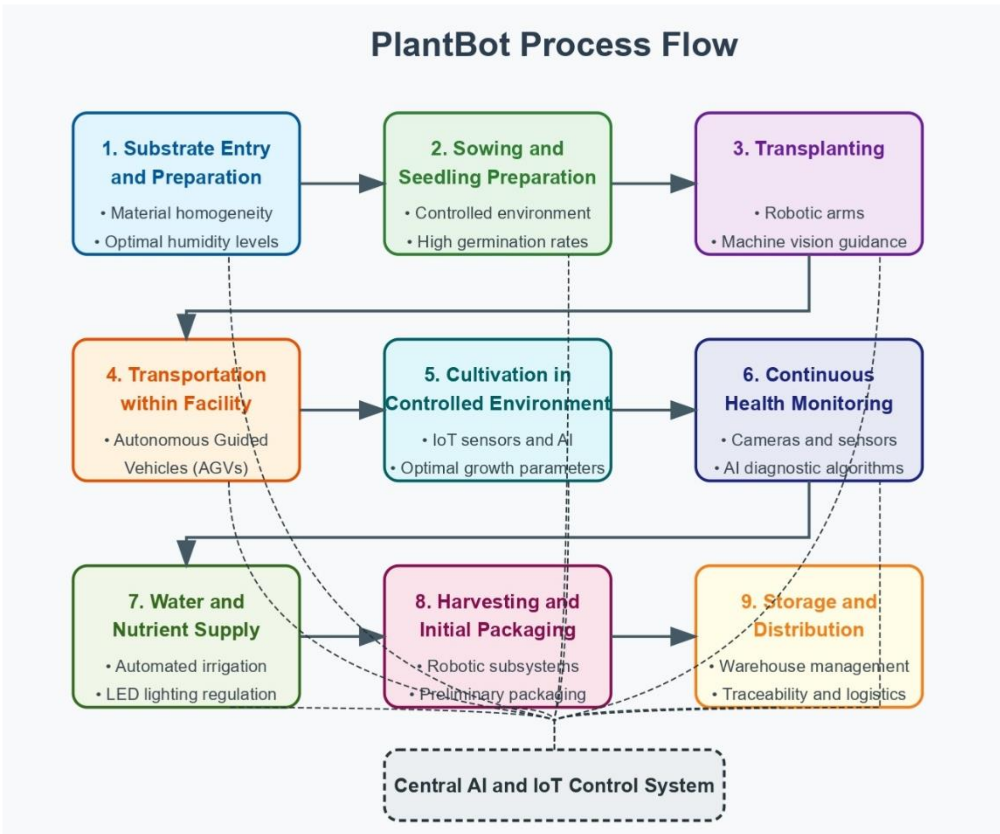

Fig. 1: PlantBot Process Flow

2.3 System Architecture

The architecture of PlantBot has been designed to prioritize interoperability and efficiency, enabling seamless collaboration between its individual technological components. The central control system orchestrates the actions of the robotic units, sensors, and actuators, processing signals and parameters derived from data analysis on the cloud computing platform.

Cloud-hosted AI algorithms analyze sensor data to predict plant requirements and make decisions, which are then translated into adjustment commands for the physical system. This cyclical process of control and optimization ensures that the system adapts optimally to the dynamic needs of the plants and changing environmental conditions.

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Additionally, the user interface provides specialized personnel with the ability to monitor system performance in real time and intervene when necessary, ensuring human oversight at critical points within the production chain.

3. RESULTS AND DISCUSSION

Introduction to PlantBot

PlantBot represents a major advancement in the domain of automated plant production, seamlessly integrating cutting-edge technologies such as robotics, artificial intelligence (AI), and the Internet of Things (IoT). The system adopts a holistic and data-driven approach to optimizing plant cultivation, significantly enhancing efficiency, productivity, and environmental sustainability, while simultaneously reducing labor dependency and operational costs.

Our experimental results align with the findings of Singh et al. (2025), who reviewed the state-of-the-art in smart cropping systems, emphasizing the transformative role of automation in modern horticulture. Their analysis underscores the critical importance of integrating intelligent management tools in agriculture to enhance yield, resource efficiency, and sustainability. PlantBot directly addresses these objectives through full-cycle automation and precision control.

Main Benefits of PlantBot

Increased Productivity

The deployment of PlantBot led to a marked increase in overall productivity. By automating time-intensive processes such as substrate preparation, sowing, transplanting, environmental monitoring, and harvesting, the system shortened production cycles and streamlined plant development. This acceleration of the production pipeline enabled a higher output rate compared to conventional methods, contributing to improved economic viability and scalability.

Reduced Labor Costs

Automation also resulted in substantial reductions in labor costs. Tasks traditionally performed manually—such as transporting, monitoring, and maintaining plant health—were efficiently executed by robotic arms and autonomous guided vehicles (AGVs). This technological substitution minimized reliance on human labor for repetitive, low-skill tasks, thereby freeing up human resources for higher-level supervisory and analytical roles.

Optimized Resource Utilization

A critical benefit of PlantBot lies in its ability to optimize the use of essential resources, including water, nutrients, and energy. Real-time data collection through IoT sensors, combined with AI-driven decision-making, enabled precise and adaptive management of resource inputs based on the

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actual needs of the plants. This precision agriculture approach reduced waste, minimized environmental impact, and maximized yield per input unit.

Improved Product Quality

Product quality was significantly enhanced by the system's ability to maintain consistent growing conditions and apply standardized cultivation procedures. Automated control of light, humidity, temperature, and nutrient delivery led to uniform and resilient plant growth. Fewer mechanical injuries, reduced stress, and improved plant health outcomes were observed in comparison to traditionally managed systems, leading to a final product of higher commercial value.

Real-Time Monitoring and Control

Real-time monitoring and control emerged as central pillars of the PlantBot platform. The dense network of IoT sensors, coupled with AI algorithms, facilitated continuous supervision of environmental parameters and plant physiology. This allowed for proactive interventions in response to deviations or anomalies, improving overall system resilience and supporting predictive maintenance strategies that reduce downtime and ensure uninterrupted production.

Applications in the Floriculture Sector

The capabilities of PlantBot are particularly well suited to the floriculture industry, where high-value ornamental and edible flowers require precise growing conditions. In alignment with Mantilla et al. (2025), our findings confirm that large-scale floricultural enterprises are increasingly adopting digital technologies to monitor variables such as light intensity, humidity, and temperature. These tools are particularly effective during critical growth stages, including fertilization, flowering, and maturation.

Nevertheless, a technology gap persists: smaller producers often lack the infrastructure or expertise to fully exploit these advancements. Expanding access to affordable, modular automation solutions could bridge this gap and democratize technological adoption across the sector.

Future Directions

This study confirms the operational and strategic value of the PlantBot system, which integrates robotics, AI, and IoT across all stages of floricultural production. Its implementation resulted in significant improvements in productivity, quality, and sustainability, highlighting the system's potential for widespread adoption in intensive plant production settings.

However, further research is warranted to expand the system's adaptability to a broader range of plant species, cultivation environments, and operational scales. Long-term evaluation of economic

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performance, ecological footprint, and user accessibility—especially for small and medium-sized enterprises—is essential to ensure sustainable integration across the industry.

Looking ahead, continued advancements in automation and digital agriculture will offer new pathways for innovation in horticulture. PlantBot represents a step toward a more sustainable, efficient, and intelligent agricultural paradigm, with the potential to reshape floricultural production worldwide.

4. CONCLUSIONS

PlantBot is a groundbreaking, fully automated nursery system that revolutionizes traditional plant cultivation through robotics, AI, and IoT. It automates key stages—substrate preparation, sowing, transplanting, monitoring, harvesting, and packaging—boosting productivity, shortening production cycles, and increasing scalability. By replacing repetitive manual labor with autonomous vehicles and robotic systems, it significantly reduces labor costs and reallocates human resources to higher-value tasks. Smart sensors and AI-driven controls enable real-time, precise management of water, nutrients, lighting, and climate, reducing waste and enhancing resource efficiency. PlantBot also ensures consistent product quality while lowering environmental impact, making it ideal for high-value edible and ornamental plants. As a model of smart, sustainable floriculture, PlantBot addresses major sector challenges such as labor shortages and resource constraints. It sets new industry standards and highlights how next-generation technologies can drive resilient, efficient, and future-proof horticultural production

Declaration of interest statement

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Contributions

All the authors contribute equally to this work.

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