Available online at
http://currentagriculturetrends.vitalbiotech.org/

ISSN (E): 2583 – 1933

Curr. Agri.Tren.:e- Newsletter, (2024) *3*(10), 29-34

Current Agriculture Trends: *e-Newsletter*

Article ID: 345

Smart Agriculture: Robotics and Artificial Intelligence for a Sustainable Future

Anurag Patel[1]*, Bhupendra Singh Pamar[2] and Deepak Kher[1]

[1]School of Agriculture, Sanjeev Agrawal Global Educational University, Bhopal- 462022
[2]ICAR-Central Institute of Agricultural Engineering, Bhopal- 462038

Article History
Received: 10. 10.2024
Revised: 16. 10.2024
Accepted: 20. 10.2024

INTRODUCTION

Agriculture is crucial for our survival and requires advanced practices and technologies, including agricultural robots, to ensure sustainable production without compromising safety for farmers and labor. Robotics are being applied in various agricultural operations, such as transplanting, weeding, spraying, and harvesting. Many agri-robots have been developed in developed countries, while research is underway in developing countries like India. Some researchers have conducted research in crop mapping, fruit identification, and disease detection using vision-based systems. Drones (UAV) are extensively used for crop health monitoring and spraying operations. However, most developed technologies are in prototype stage, requiring further research and development to bring these technologies to farmers' fields for sustainable production with minimal manpower. This article emphasizes the available robotic systems for various farm operations, either in the field or horticultural crops.

Seeding and planting

Robotic transplanters are a potential solution for manual vegetable transplanting (Fig. 1), saving time and requiring less labor. These systems use computer graphics or machine vision to simulate the transplanting process, consisting of a robotic arm for seedling pick-up, a path manipulator, and an end-effector. The intelligent transplanting system includes a fixed gear train, seedling tray conveying mechanism, planting mechanism, and seedling detection system using a programmable logic controller (PLC). This ensures precision, safe, and comfortable operation for vegetable and crop transplanting.

ISSN (E): 2583 – 1933

Fig. 1. Vegetable transplanting

Intercultural

Weed monitoring techniques like patch spraying and site-specific weed control use automatic image processing and mapping, but face challenges due to leaf forms. Weedcer calculates weed coverage and uses Adigo's GPS-guided field robot for data collection. AI-driven robots use deep learning for precise weed identification and elimination without harming crops. These robots effectively manage herbicide-resistant weeds in dense fields, eradicating weeds before they mature and disperse seeds.

1. Robots for precise weeding

Intercultural weeding involves manual or mechanical weeders or chemical spraying, which is considered the most drudgerious farm operation due to its high labor demands and environmental degradation. Robotic weeding (Fig. 2), which uses vision-based systems for weed detection and mechanical uprooting, may offer a potential alternative due to strict protocols and herbicide restrictions. Co-robots developed by the US National Science Foundation can work as human partners, performing tasks jointly with ease. This technology could be a more sustainable and environmentally friendly alternative to manual weeding.

Fig. 2: Robot Weeders

Spraying

Contamination is a major issue in agro-chemical spraying, potentially threatening human health. Robotic sprayers are being developed for target-oriented application in orchards and greenhouses to enhance input use efficiency. Currently, pesticides are applied uniformly across fields, despite uneven distributions of pests and diseases. Effective site-specific application of pesticides can reduce the amount used in precision horticulture (Fig. 3). An automatic variable-rate sprayer requires accuracy in location, canopy size, and adquisition of agro-chemicals to reduce environmental losses and save inputs. Autonomous systems can also reduce labor requirements, increasing crop yield, agricultural profitability, and economic survival.

ISSN (E): 2583 – 1933

Fig. 3: Spraying with drones

Smart irrigation system

Agriculture accounts for 70% of global water usage, making it crucial to develop effective strategies for optimizing water usage in irrigation. As the world's population grows, so does the demand for food. Traditional methods of irrigation have been replaced by automated scheduling systems that consider factors like crop characteristics and meteorological variables. These autonomous systems aim to reduce resource consumption, increase productivity, and enhance efficiency with minimal human intervention (Fig. 4). Wireless drip irrigation systems automate irrigation in agricultural fields, while sensors for soil elements like potassium, phosphorus, fertility, and pH monitor soil fertility levels. This approach integrates data on groundwater levels, soil conditions, nutrient requirements, and weather forecasts to optimize water usage while preserving soil health and structure.

Fig. 4: Smart irrigation

Harvesting with robots

Automated harvesting, which uses robots with prosthetic limbs and computer vision to gather fruits without damage, is being developed to address labor-intensive tasks in the agricultural field. While robots have been tested for various crops like strawberries, tomatoes, and oranges, challenges persist in harvesting from hedges and arboreal plants. Brexit and COVID-19-related labor concerns in the UK have highlighted the need for robotic harvesting to address workforce shortages, particularly in the soft fruit industry (Fig. 5). Fruit selection and detachment are essential tasks for efficient harvesting. Most robotic harvesters are designed for fruits like apple, citrus, cherries, strawberries, and tomatoes, but some have been developed for greenhouse crops.

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Fig. 5: Robotic fruit harvester

Crop health monitoring

Advancements in sensing and imaging technologies have revolutionized farming practices, enabling farmers to enhance crop productivity and minimize plant damage. Drones and autonomous ground vehicles equipped with high-resolution cameras and detectors are increasingly used for surveying, data collection, and analysis (Fig. 6). These aerial robots can detect agricultural diseases, pests, nutrient deficiencies, and water shortages. While satellite imagery is used for aerial surveillance, drones offer more precise and versatile data collection methods.

Fig. 6: Drone crop health monotring

Unmanned arial vehicle

Drones, also known as Unmanned Aerial Vehicles (UAVs), are a new technique for agricultural operations, such as crop mapping, scouting, and spraying, in areas with limited labor. UAVs offer high spatial resolution, independent of cloud cover factors, and instant information communication. They are used for determining shrub utilization, mapping grass species, measuring shrub biomass, and mapping crop vigor. UAVs can also be used for vegetation mapping, weed detection, crop water stress monitoring, biomass recording, and evaluating nitrogen treatments (Fig. 7). They can also be used as geo-fencing to protect against animal attacks. In India, drones have reduced production costs by 25-30% by early detection of pests and efficient spraying. This aerial robot-based spraying system allows farmers to apply agrochemicals safely and in time.

ISSN (E): 2583 – 1933

Fig. 7: UAV for various operations

Unmanned ground vehicle

Unmanned ground vehicles (UGVs) are increasingly being used in agriculture due to their ability to navigate through unpredictable terrain. However, the instability of these robots can be compromised by their interaction with the terrain. Despite this, ground mobile robots (UGVs) have shown advantages in various industries, such as mining, farming, and forestry. The global navigation satellite system (GNSS) has facilitated the configuration of autonomous vehicles, particularly in agriculture. However, these systems do not grant vehicles or tools autonomy. Integrating safety systems, such as obstacle detection and safeguarding humans and animals, is crucial for UGV configuration. Enabling robot communication with operators and external servers through wireless communications, including cyber-physical systems (CPSs) and IoT techniques, is essential for incorporating decision-making systems based on big data analysis. This integration will facilitate the expansion of decision processes into fields like machine learning and artificial intelligence (Fig. 8). As smart factories rely on intertwined concepts of CPS, IoT, big data, and cloud computing, UGVs for smart farms should follow suit to minimize traditional delays in technology application to industry and agriculture. The technology necessary to deploy more robotic systems in agriculture is readily available, offering clear economic and environmental benefits.

Fig. 8: Unmanned ground vehicle

Challenges and opportunities

Robots are increasingly being used in agriculture to provide food security and address labor shortages. These machines can perform repetitive tasks like transplanting, weeding, and harvesting, offering advantages over limited labor. Drones can also assess crop management, enabling better crop planning and monitoring. However, adoption and commercialization are challenges due to climatic and geographical conditions, high costs, and the need for skilled operators. Some commercially available robotic applications include fruit harvesters, sprayers, and autonomous combines. Challenges include limited battery life, cost, licensing, and stability. The global robot market is expected to grow, but challenges like uneven industrialization distribution and limited access to resources in rural areas may hinder its widespread adoption. The integration of robotics and artificial intelligence in agribusiness is still in its early stages, and concerns are mounting about its potential impact on farmers and the wider community.

CONCLUSION

The agricultural production system has seen transformative changes due to advancements in robotics and artificial intelligence (AI). The labor shortage during peak seasons has driven the integration of technologies like IoT, machine learning, and robotics in various operations, including transplanting, weeding, spraying, and harvesting. While robotic systems hold great potential, they are still in the developmental stage, and further research is necessary to refine these technologies for large-scale adoption. This technology-driven approach aims to enhance productivity, sustainability, and efficiency in agriculture. However, challenges remain in terms of cost, operator skills, and environmental adaptability. Collaborative efforts and responsible innovation are essential for addressing these barriers and ensuring that the benefits of robotic technologies are realized without causing social or ethical harm to farmers and communities.