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Review Article

Robotic solutions for precision agriculture

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ABSTRACT: The robotic system is a key component in modern agriculture. The article aims to expand robotic solutions for precision agriculture and improve productivity, resource utilization, decision-making, sustainability, and farmworker safety. It aims to automate repetitive tasks, gather real-time data, promote sustainable practices, and reduce risks for farmworkers. They offer numerous potential solutions to issues related to the growing global population, changing demographics, and economic status. This article investigates how robotic systems can be significant to precision agriculture. Traditional farming is facing issues such as climate change, resource depletion, labour shortage, etc. The use of robotic systems makes precision agriculture achievable and it provides a sustainable solution. This study examined the importance of robotics in agricultural processes such as planting, seeding, weeding, and harvesting. The potential benefits of robotic solutions, such as increased efficiency, reduced labour costs, and improved crop yield, are explored. The article identifies key challenges and opportunities associated with robotic implementation in agriculture. The research aids in creative effective agriculture techniques by imaging the future use of robotics in agriculture.

Keywords: Improve productivity, robotic system, modern agriculture, precision agriculture, sustainability.

INTRODUCTION

Agriculture contributes significantly to the world's economy (Praburaj *et al*., 2018). The oldest and most significant economic activity for humans is agriculture, which provides the fuel, food, feed, and fibre essential to survival (Lough *et al*., 2016). The demand for food has increased dramatically in terms of both quantity and quality due to the world's population growth. The need for efficient and sustainable agricultural operations has grown as a result of the growing global population and the resulting demand for food production (Emmanuel *et al*., 2023; Pawlak and Kołodziejczak, 2020). Precision agriculture is a sustainable method for ensuring food security, reducing labour and energy consumption, and improving environmental management by efficiently applying seeds, fertilizers, and agrochemicals (Mahmud *et al*., 2020). An "Agribot," or agricultural robot, is a robot that uses technology in agriculture. The use of robots in agriculture has significantly enhanced agricultural production and output in several nations, with lead time and operational expenses of agriculture drastically decreasing (Vamshidar Reddy *et al*., 2016). The employment of robots for agricultural harvesting is one sector that has shown rapid progress in recent years. Hence, robots that harvest crops for agriculture are now observed to be growing in popularity since they provide benefits including improved precision, efficiency, and lower labour costs. The term "robot" can be associated with various images, such as Star Wars characters R2D2 and C3PO, human-like machines like Rosie from The Jetsons, or the Rover Sojourner from the Mars Pathfinder mission (Stanford University, n.d). Some view robots as dangerous technological advances, potentially leading to human extinction by outwitting or outmaneuvering man, or making humans too reliant on technology, while programming robots to entirely perform farm work. Robotics facilitates and supports integrated technology in numerous elements of people's lives today, and examines technological concepts that connect every aspect of human life (Umam *et al*., 2019). The increasing number of people worldwide means that there is a constant need for more food. By 2050, when it is expected that there will be more than 9 billion people on the planet, it was claimed that agricultural productivity, especially in field agriculture, has to rise by 70%. (Botta *et al*., 2022). The sustainability of the environment and farmers' earnings are jeopardised when there is a simultaneous growth in agricultural activity and the waste and exploitation of fertilizer, irrigation water, and other phytosanitary goods. Robotic systems are described as those that employ a variety of sensors, actuators, and human interfaces to interact with their environment, including people, to give intelligent services and information. Robots can perform tasks that humans cannot, and can be beneficial in many ways and operations. However, their widespread deployment in industries like agriculture, military, and healthcare, by assumption may lead to job losses and unemployment (UKEssays, 2019). Proper research and development are needed for the efficient use of robot technology. Ultimately, robots can be beneficial in the workplace when they balance practical necessities and greed, ensuring that they are used efficiently and effectively. Thus, precision agriculture is a modern farming idea that gathers data from plants and their surroundings using sensors and information technologies. To maximize the circumstances for plant development and yield, this data is then examined. Data about weather, root water content, and soil conditions may all be gathered via sensors. Then, using this data, operations like pest control, fertilization, and irrigation are automated. Maximizing production and establishing ideal growing conditions for plants are the objectives of precision agriculture (Afrimash, n.d). Precision agriculture is important because it can improve crop quality, manage pests and diseases, boost harvest yields, lengthen production cycles, and improve sustainability. This article aims to expand robotic solutions for precision agriculture and improve productivity, resource utilization, decision-making, sustainability, and farmworker safety. It aims to automate repetitive tasks, gather real-time data, promote sustainable practices, and reduce risks for farmworkers.

Challenges of traditional agricultural practices

Fifty per cent of farmers worldwide currently cultivate using traditional methods, which highly value indigenous knowledge and environmental harmony (Hamadani *et al*., 2021). It involves conventional tools, natural resources, organic fertilizers, and cultural values. The advantages are improved soil fertility, carbon storage, biodiversity conservation, resource efficiency, sustainability, and environmental protection (Hamadani *et al*., 2021). Notwithstanding, there is a growing recognition of these techniques as sustainable means of producing food. It is becoming more difficult for many traditional farming communities to feed their populations, much alone producing marketable surpluses of agricultural goods to help pay for much-needed and long overdue rises in living standards (Floyd *et al*., 1969). "To transform traditional agriculture, which is niggardly, into a highly productive sector of the economy," is the responsibility that follows. Traditional farming methods and even some modern ones can impede sustainability by causing deforestation, water pollution, greenhouse gas emissions, and soil degradation. Sustainable agriculture offers an alternative because it uses fewer chemicals, protects biodiversity, and improves soil health. Traditional farming faces challenges such as preserving output, meeting social demands, surviving on less water, assessing new opportunities, depleting resources, climate change threats, women's emancipation, war, and urbanization, while often optimizing yield without considering environmental and societal impacts (SCISPACE, n.d).

THE EMERGENCY OF PRECISION AGRICULTURE

Precision agriculture (PA) is the science of enhancing agricultural yields and supporting management choices using advanced sensor and analytic technologies. The globe has embraced PA, a novel idea that promises to boost output, cut down on labour costs, and guarantee efficient control of irrigation and fertilizer systems (Taylor *et al*., 2023). It makes use of a lot of data and information to enhance crop quality, yields, and the utilization of agricultural resources. Precision agriculture uses high-resolution satellite photography and geospatial tools and sensors to spot differences in the field. The exorbitant cost and scarcity of this type of imaging, however, indicate tiny unmanned aircraft systems or low-altitude remote sensing platforms as viable alternatives because of their flexibility, high resolution, and cheap operating costs (Zhang and Kovacs, 2012). The most popular use of unmanned aerial systems (UAS) is precision agriculture. Regarding agricultural management issues, high-spatial-resolution UAS imaging allows for faster and more economical detection, diagnosis, and remedial action than low-resolution satellite imagery. Precision agriculture employs cutting-edge technology to minimize expenses and their negative effects on the environment by making effective use of fuel, land, water, fertilizer, and pesticides (Association of Equipment Manufacturers, 2024).

The role of automation in precision agriculture

Automation is the main idea. It alludes to the use of technology to carry out manual tasks that would normally need human intervention, the robot systems are one of the technologies used in carrying out specific tasks (Vaucanson, 2024). Precision farming operations and the replacement of people in certain activities are now possible with the development of agricultural robots. They are classified into two categories: robotic smart tools carried by vehicles and self-propelled mobile robots. Robots such as tractors, sprayers, and combined self-propelled harvesters have been automated through the use of Global Positioning Systems (GPS)/Global Navigation Satellite Systems (GNSS) auto-guidance systems (Hajjaj and Sahari, 2016). This might include digital operations like sending emails automatically or physical tasks like building vehicles on a production line. Automation is the application of machines to jobs formerly undertaken by human beings or, increasingly, tasks that would otherwise be impossible. Utilizing various precision agricultural technologies, such as VRT, GNSS, robotics, drones, and AI, automation of crop production is possible (FAO, 2022). It could be essential to gather geographical data to utilize information from crop simulation models and a geographic information system (GIS) to determine the number of inputs required to maximize profit and yield. Agriculture is crucial for the global economy, as population growth increases food demand. Precision agricultural robots can help reduce soil compaction, lower carbon dioxide emissions, improve weed control, minimize soil damage and water pollution, and optimize crop yields. They can also support multi-cropping practices, and enhance natural pest control, biodiversity, and crop yields (Bose, 2013). These robots can be programmed to analyze, automate, and perform repetitive tasks, making them an essential tool for addressing the growing global food demand (Praburaj *et al.,* 2018).

Uses of robotics resources

Agricultural robots' applications could be used for several agricultural processes that are more effective and productive. Robotic systems could be used for several purposes, which include weeding, planting, fertilizing, and spraying pesticides (Bernier, 2023). Similarly, agricultural robots are useful for harvesting as well as for planting various crops and providing irrigation (Mwangi, 2023). Without question, employing agricultural robots boosts output while lowering the amount of physical work required. Agricultural drones increase production, give flexible visualization, and promote economic growth through video, specialized video, targeted video, and agricultural spraying systems.

Agriculture is being transformed by agricultural robots, that offer efficiency and accuracy to a variety of jobs. Robots with sensors and GPS are used in precision farming to maximize crop yields while reducing waste by using water, fertilizer, and pesticides in the best possible ways (Zhang *et al*., 2022). Tomato Picking Robots and Robotic Strawberry Harvesters are two examples of automated planting and harvesting systems that expedite labour-intensive procedures by cutting down on physical work and produce damage (Carvalho *et al.,* 2023; Yang *et al*., 2023). Robots are good at eradicating weeds and pests because they can target particular problems using machine learning and computer vision, which eliminates the need for common pesticides (Yang *et al*., 2022). Robots equipped with cutting-edge sensors for soil and crop monitoring offer real-time data that helps make better judgments about fertilization and irrigation (Lopez *et al*., 2023; Wang *et al*., 2023). Furthermore, milk and feed activities are automated by robotic systems in livestock management, increasing output and promoting animal welfare (Jones and Smith, 2022; Lee *et al*., 2023). In general, agricultural robots improve modern farming's productivity, sustainability, and efficiency.

Advantages of robotics solution

Agricultural robots have transformed farms' performance levels by ensuring round-the-clock surveillance and other activities, increasing yields, and relieving farmers of tedious tasks. They gather data in real time, facilitating well-informed judgments and practice optimization (Bazargani and Deemyad, 2024). Robots offer fast and precise solutions while boosting efficiency and output without becoming sick or tired. Integrating cameras and sensors into robots can help to keep a close monitor on farms to identify animal illness and pests' infestation of crops. In addition, errors are also reduced by the task-specific orientation of robots with information from seeds, crops, weather, and soil, forecasting outcomes for precise decisions (Moundekar *et al*., 2020; Bello *et al*., 2020; Fan *et al*., 2020). The use of robots makes farming duties appealing to non-agricultural people, also opening up new career options. Large-scale data are analyzed using Artificial Intelligence and machine learning to spot patterns and anticipate issues. Hence, informing better approaches to resolve certain risks. The direct effect of this could be

Figure 1. Robotic Transplanter (Source: Bernier, 2023).

Figure 2. Crop Harvesting Robots (Source: Mwangi, 2023).

Figure 3. Aerial crop disease drone (Source: Jordon, 2017).

experienced in reduced use or abstinence of chemicals having environmental effects, swift actions towards water conservation, and decreasing soil compaction through automated planting and tilling and other deliberate activities for the sake of sustainability (FAO, 2020). There are other numerous applications for agricultural robots. Recently, automated fruit picking has been made easier with the use of autonomous mobile robots (AMRs) that use flexible grippers and sophisticated 3-D vision systems (Plant Engineering, 2019). Other applications for agricultural robots include robotics planting, robotics spraying for weed control, and robotics pruning and thinning. Robotic weeding systems have shown that precision farming has the potential to reduce the existing reliance on agrochemicals like pesticides and herbicides, hence boosting sustainability and lowering environmental pollution (Wu *et al*., 2020). Automated smart harvesters could gather crops from fields where robots are bringing accuracy, efficacy, and efficiency to the fore (Fahmida *et al*., 2022). Robots automatically pick certain popular fruits and vegetables, such as apples, tomatoes, sweet peppers, kiwifruit and litchi. Figures 1 to 3 show the advantages of using robotics systems to carry out agriculture processes. The most difficult task in high-value crop fields is automatic path navigation, which requires localization, mapping, tracking, and path planning (Wang and Liu, 2020). Generally, robust path navigation determines the path from track pictures (taken with an RGB-D camera) by detecting the object's colour (Basri *et al*., 2021). Pruning is a crucial agricultural procedure that entails the deliberate removal of certain plant elements, such as branches, buds, or roots (Jakhwal *et al*., 2024). Pruning is a good candidate for robotic automation (You *et al*., 2024).

Challenges and opportunities in implementing agricultural robotics

There are several challenges associated with the use of robot systems in agriculture and farm productivity which include the high cost of agricultural robots, environmental issues, and implementation of agriculture robots. Certain robotic technologies used in agriculture come at a high cost. The average cost of a fruit-picking harvesting robot is between $250,000 and $750,000, which makes it out of reach for subsistence farmers, especially those in low-income nations (Markets and Markets, 2023). Big equipment is only practical in large farms, which causes problems for smaller farms both financially and environmentally. Larger equipment requires more capital, is more costly, and has reliability problems (Pedersen *et al*., 2008). For robots to operate accurately and effectively, maintenance is required and it is always expensive (Mitchell, n.d). Robots are less suited for jobs requiring creativity and problem-solving because they lack the intuitive and creative thinking skills of humans. Robots are not able to think on their own; they can only carry out instructions (Dikshita, n.d). Due to their serial character, small and medium-sized farms confront environmental and economic issues. Incorporating agricultural machinery, establishing wireless connectivity, developing robot software for agriculture robots, putting in place efficient human-robotic interaction tools, and enabling

Figure 4. Horticulture robotics (Source: McCullough, 2023).

Figure 5. Weed control robotic (Source: Brazeau, 2018).

software reusability and reliability are all necessary for the practical implementation of agriculture robots (Hajjaj and Sahari, 2016). The use of human labour or teleoperated robots is also limited due to the physiological constraints of humans and the shortcomings of interfaces used to control robots (Yerebakan and Hu, 2024). The challenges of robotics design are numerous and the growing number of sensors and computational resources in smaller robot packages is leading to an increase in complexity in robotic hardware designs (Sofge *et al*., 2003; Pedersen *et al*., 2008; Yadav *et al*., 2020) Zheng *et al*., 2022).

Future of robotics in precision agriculture

Robotic farming offers a promising future for production,

Figure 6. Apple harvesting robotics (Source: Royal, 2024).

sustainability, and efficiency. It minimizes resource usage, reduces chemical runoff, and promotes environmentally friendly farming methods (Krishna, 2024). Agricultural robotics use AI to optimize tasks like planting, weeding, harvesting, and crop observation, including drones and self-driving tractors. Robotics and artificial intelligence developments have revolutionized agriculture by solving manpower shortages and advancing sustainable alternatives. Machine learning and robots are employed for more accurate planting, harvesting, and weeding (Khadatkar *et al*., 2022). Artificial intelligence techniques are expanding and improving decision support (Mariani *et al*., 2023) These techniques include coordinating data delivery, forecasting, analyzing trends, quantifying uncertainty, anticipating the user's data needs, providing information in the most appropriate forms, and suggesting courses of action(Soori *et al*., 2023)This procedure will raise agricultural productivity levels. As technology develops further, these robotic arms are expected to become more important to agricultural production (Gofman and Jin, 2024) They will significantly contribute to developing inventive, sustainable, and efficient farming methods, ushering in a new era in agricultural technology. Robotic systems will play a critical role in agriculture in the future, improving yields, sustainability, and efficiency (Ajami and Karimi, 2023). These precision-tasked, resource-optimized, environmentally friendly, and autonomous tractors, drones, and specialist robots will yield higher-quality crops. Drones and robotic transplanters automate chores, but further research is required to create next-generation robots that can do difficult agricultural jobs. Figures 4 and 6 show that the robotics system is the future of precision agriculture.

CONCLUSION AND RECOMMENDATION

In summary, the future of agriculture will increasingly rely on these technological advances; embracing and advancing robotic technologies will be crucial for achieving sustainable and productive agricultural practices. Agricultural robots are essential in advancing modern farming by addressing pressing challenges like climate change, resource depletion, and labour shortages. Their ability to automate tasks like planting, seeding, weeding, and harvesting enhances efficiency, reduces labour costs, and improves crop yields.

It is recommended that governments and agricultural firms adopt a comprehensive approach to robotic integration into agricultural practices to ensure sustainable agricultural development. Both government, agricultural firms, and researchers are therefore encouraged to look in a direction that proactively addresses the lingering challenges of sustainable agricultural development. To advance robotic systems in agriculture, research and development investment is vital. Practical integration will be improved by cooperative efforts between developers, farmers, and legislators. To improve technologies and demonstrate their efficacy, field tests, experiments, and education programs are key. Implementation will be more effective if it addresses the ethical, economic, and labour implications and promotes sustainable behaviours.

COMPETING INTEREST

The authors declare no form of competing interest.

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