Research Output Journal of Biological and Applied Science 3(2):28-31, 2024

ROJBAS Publications ONLINE ISSN: 1115-9200

https://rojournals.org/roj-biological-and-applied-science/ PRINT ISSN: 1115-6120

The Role of Robotics in Agriculture: Enhancing Productivity and Sustainability

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ABSTRACT

The integration of robotics in agriculture has emerged as a transformative approach to addressing the challenges of increasing productivity and sustainability. As global populations rise and arable land decreases, the adoption of robotic technologies offers solutions to optimize agricultural practices, reduce labor dependency, and minimize environmental impact. This paper explores the multifaceted role of robotics in modern agriculture, highlighting the benefits, challenges, and future trends of robotic systems. Key applications include precision farming, automated harvesting, and smart irrigation, all of which contribute to a more efficient and sustainable agricultural sector. Despite the promising potential, there are significant hurdles to overcome, including high costs, technological limitations, and the need for tailored solutions across diverse agro-ecological environments. The paper concludes with a discussion on the future prospects of agricultural robotics, emphasizing the importance of innovation and collaboration in driving the field forward.

Keywords: Agricultural Robotics, Precision Farming, Automation in Agriculture, Sustainable Agriculture, Smart Irrigation, Robotic Harvesting.

INTRODUCTION

From the ancient times, robotics has always played an important role in agriculture until now. It is very necessary now as the agricultural land is decreasing as the population increases. Through the use of robotics in agriculture, productivity can be increased as it helps to reduce crop damages, reduce the cost of labor, and increase the rate of production. As the labor in the agricultural field is decreasing, it becomes a necessity to use robots or some sort of automation in agriculture to increase productivity and make it sustainable [1, 2]. Agriculture is the primary concern for any country's economic development. Since most of the countries have a huge workforce in agriculture, there are many agricultural practices where one cannot find a chemical solution. In that case, the robotic system will provide an effective way of finding the disease-prone areas and effective precision crop management. A large number of agricultural vehicles have been developed for agricultural field operations until now. Among them, the number of tractors and drip irrigation vehicles is increasing. The necessity of robotics in agriculture is doing a lot in soil recognition and seed sowing process. Robotics can help them do that better. "Robots will be a more rational and effective solution for agriculture. Although in the early stages of development, they are quite difficult systems, in the medium term, agricultural robots will become a very profitable investment. Robotic applications, therefore, contribute to the provision of increasing sustainability across the whole sector of agriculture [3, 4].

BENEFITS OF IMPLEMENTING ROBOTICS IN AGRICULTURE

There are many benefits of operational robotics in agriculture. The essential ones are improved cost and resource efficiency, less dependency on and need for human labor, and positive effects on environmental sustainability. Robotics can apply exact actions and operations wherever and whenever needed to support or enhance the main agricultural operational cycle. By performing operations like disking, plowing, planting, weeding, spraying, and harvesting more precisely, robotic solutions can reduce the use of inputs

such as diesel, seeds, chemicals, fertilizers, and irrigation water. This directly leads to cost savings, reduced negative environmental impact, and higher production efficiency [5, 6].

Work is needed to optimize and increase the speed and safety of robotic operations. This will lead to further commercialization of agricultural robotics and other benefits for the agricultural sector, such as the potential for predicting and preventing machinery breakdowns, delays, and downtimes for maintenance and repair, as well as avoiding soil compaction. Although the thorough operation of agricultural robotics is not yet fully implemented and commercialized, automation for repetitive operations does exist. All indications are that the upcoming generations will be much more versatile, affordable, and easier to operate than current models [7, 8]. The application of robotics in agriculture has played an increasingly significant role in enhancing crop yield and quality over the past decades, making it easier to control the influence of external factors. Agricultural production technologies in China have been continuously improved and modernized to meet the increasing demand [5, 9].

CHALLENGES AND LIMITATIONS OF ROBOTICS IN AGRICULTURE

Although robots can play a very important role in agriculture enhancement, there are a number of constraints to their implementation and use. Key obstacles envisaged by the stakeholders that have a direct impact on the acceptance of new technologies are their high investment and maintenance costs, necessity of new or modified infrastructure, lack of effective development of robotic systems for specific agro-ecological conditions and operation. By now, the efficiency of using robots is indeed constrained by limited autonomy and lack of effective control over target operations. The summary evaluation of the feasibility of robotic systems shows that the majority of them need at least 3-5 more years for development until they are ready to operate under various location scenarios, crops and tasks. In addition, some robotic systems are also constrained by their working speed and slow operation [10]. Altogether, the hype and high expectations that are outside the reality are not helping the acceptance and practical usages of robots driven by policymakers without the proper and accurate knowledge of how applications could be dealt in specific regions. Moreover, the pilot applications of autonomous robots in Europe and worldwide are new for companies, ICATs, suppliers and peasants. It is essential to be aware of the technical and scientific key limitations and challenges for all the stakeholders involved in the great challenges of how to address and overcome these limitations by working altogether in a concerted and harmonized way. In this context, we need to be conscious of the boundaries under which the adoption and use of such systems are feasible. By acknowledging these aspects, a more realistic plan for the integration of robotics in agriculture may be expected [11].

INNOVATIVE APPLICATIONS OF ROBOTICS IN AGRICULTURE

This special issue mainly focuses on the novel and unconventional applications and scientific topics in the use of robotics in agriculture. In this section, we will present an overview of applications from authors presenting some innovative approaches that deploy robotics to harvesting, terminating plant roots, performing non-destructive phenotyping, providing support in monitoring and making decisions on managing water, and weeding. The authors mainly focus on using robotics to plant seeds, remove fields, harvest, monitor, and provide support in decision-making in scientific projects. The results of these works have confirmed the timeliness of using advanced technologies in the field of agriculture [12, 13]. An international group of authors used robotics for other purposes, in particular for agrobiomonitoring, water power management, weed detection, seeding, and carrot harvesting. The drone is used for remote monitoring of harmful vegetation, and robotics, which are embodied in two application-specific agricultural vehicles—magnetic systems and electronics—are used to terminate the burial and destruction of the roots of grain crops. Using an autonomous mobile robot, the task of the space detection of beets in the field was performed. Agriculture in the arid region and a database system to support decision-makers was analyzed in the project described by Mehraein and Müller, involving the use of a "smart" greenhouse with various sensors including robotics implementation as well as end-to-end storage, processing, and information extraction ICT solution deployment to improve understanding of the associated groundwater flow management. The focus of this article will be on other aspects of robotics use [14, 15].

FUTURE PROSPECTS AND TRENDS IN AGRICULTURAL ROBOTICS

Today, there are rapid advances in technology and within the next few years, there may be incredible transformations in terms of what can be engineered and utilized in robotic systems. Robots are among us and are being used to perform isolated agricultural tasks. Each robot is utilized within a well-controlled environment and has a specifically designed function [16]. In five years, a sweep of robots during a field would possibly be standard, with objects detected, identified, and tracked by machines at intervals and across a field, the observe being recorded when necessary. Each angle of the robotic agriculture field is

also adjusted to shake up existing practices, like spraying or analyzing plants, that produce the robots that to return. Indeed, one crop on one farm can export a full scope of physical, sensors, and knowledge challenges unique to every farm and crop type. Where the future is probably going to align within the field of robotic technology is during the development of integrated systems that enable applied physical and sensor science to be undertaken with concomitant live feedback. As additional science is published, and the science base becomes refined, integrated systems can decrease technology taking over and providing recommendations and management systems improves to permit a more precise application, the additional options of the technology will match with the problem in order to provide the solution [17]. Scientists and engineers are likely to need to work a lot more closely together in the future to produce true customized agriculture production equipment. This would need a directive assessment of problems to be solved, not technology that can be developed [18].

CONCLUSION

The deployment of robotics in agriculture presents a significant opportunity to enhance productivity and sustainability in the sector. By automating key processes such as planting, monitoring, and harvesting, robotics can reduce the reliance on human labor and improve resource efficiency. The environmental benefits, including reduced chemical usage and more precise irrigation, align with the broader goals of sustainable development. However, realizing the full potential of agricultural robotics requires addressing challenges related to cost, technological advancement, and adaptability to diverse agricultural conditions. As the technology continues to evolve, it is crucial for stakeholders—including scientists, engineers, policymakers, and farmers—to collaborate closely to overcome these barriers. Future advancements in integrated robotic systems will likely play a pivotal role in shaping the next generation of agricultural practices, ensuring that they are more efficient, sustainable, and capable of meeting the global food demand.

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CITATION: Claire Niyonzima K. The Role of Robotics in Agriculture: Enhancing Productivity and Sustainability. Research Output Journal of Biological and Applied Science, 2024 3(2):28-31