

Robotics in Harvesting and Farm Management

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INTRODUCTION

Agriculture has always been the backbone of human civilization. However, with the rising global population, climate change, and decreasing availability of skilled labor, traditional farming practices are facing serious challenges.



In response, robotics in agriculture has emerged as one of the most transformative innovations of the 21st century. Modern agricultural robots are no longer futuristic concepts; they are practical tools that perform essential farm operations such as planting, irrigation, monitoring, harvesting, and post-harvest management. These machines use artificial intelligence (AI), machine vision, sensors, GPS, and IoT systems to perform tasks with high precision and minimal human intervention. The integration of robotics into farming is reshaping agriculture into a data-driven, automated, and highly efficient system, often referred to as *smart farming* or *Agriculture 4.0*.

Evolution of Robotics in Agriculture

Agricultural robotics began with basic mechanization like tractors and harvesters and has progressed into intelligent systems with decision-making abilities. Currently, robotics is widely applied in harvesting, weeding, planting and crop monitoring, with harvesting being the most advanced application area.

Key stages include:

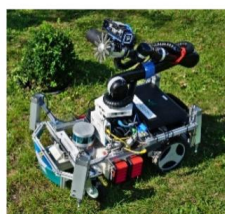
- Mechanization Era: Simple machines such as ploughs and combine harvesters
- Automation Era: GPS-guided tractors and automated irrigation systems
- Smart Robotics Era: AI-powered autonomous robots and drones

Modern capabilities include:

- Crop health detection
- Weed identification
- Selective fruit harvesting
- Real-time soil monitoring

Robotics in Harvesting Systems

Harvesting is one of the most labor-intensive and time-sensitive operations in agriculture, and robotic harvesting systems have been developed to address this challenge. These systems typically work through an integrated setup where a vision system using cameras identifies ripe crops, followed by AI algorithms that assess maturity and quality. Robotic arms then carefully pick fruits or vegetables, while a navigation system enables movement through fields or orchards. Such robots are commonly used for harvesting crops like apples, strawberries, tomatoes and peppers. They employ selective harvesting technology, meaning only ripe produce is picked, which helps reduce waste and improve overall quality (StartUs Insights). The main benefits of robotic harvesting include faster harvesting speed, reduced dependence on human labor, lower post-harvest losses and the ability to operate continuously 24/7.



(a)



(b)



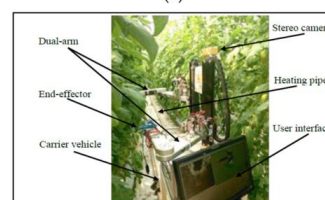
(c)



(d)



(e)



(f)

Robotics in Farm Management

Farm management involves multiple activities beyond harvesting, where robotics plays a vital role in improving efficiency and precision. Key applications include soil monitoring and analysis, irrigation management, fertilizer and pesticide application, crop health monitoring, and weed control. Equipped with advanced sensors and AI, agricultural robots collect real-

time field data to support precise decision-making. For instance, drones are used to scan large fields for pest detection, ground robots assess soil moisture levels and smart sprayers apply chemicals only in targeted areas. These technologies help optimize resource use while significantly reducing chemical consumption and environmental impact (Farmonaut®).



Technologies Behind Agricultural Robotics

Agricultural robots are built on the integration of several advanced technologies that enable precision and autonomy in farming operations. Artificial Intelligence (AI) plays a central role in decision-making, crop recognition and yield prediction, while machine vision systems allow robots to accurately identify fruits, weeds and plant diseases. GPS and navigation systems ensure precise movement and operation across large agricultural fields. The Internet of Things (IoT) connects sensors, machines and devices, enabling real-time data collection and exchange for better farm management. Robotic arms and specialized end-effectors are used for tasks such as picking, cutting, and handling crops with care and accuracy. In addition, drones or unmanned aerial vehicles (UAVs) support aerial monitoring, field mapping and targeted spraying. Together, these technologies form highly efficient autonomous farming systems that significantly reduce the need for human intervention while improving productivity and resource efficiency.

Advantages of Robotics in Agriculture

The adoption of robotics in farming offers several significant benefits that enhance both productivity and sustainability in agriculture. One of the major advantages is improved labor

efficiency, as robots help address the growing shortage of agricultural workers. They also contribute to higher productivity since machines can operate continuously without fatigue or breaks. Robotics supports precision agriculture by ensuring the efficient use of inputs such as water, fertilizers and pesticides, thereby reducing wastage. Over time, this leads to cost reduction through lower dependency on labor and optimized resource utilization. Additionally, the use of robotic systems promotes environmental sustainability by minimizing chemical usage and reducing overall environmental impact. Another key benefit is improved crop quality, as selective harvesting techniques ensure better grading, reduced damage and higher market value of produce.

Challenges and Limitations

Despite its numerous advantages, the adoption of agricultural robotics is still limited by several challenges. One of the major constraints is the high initial cost of robotic systems, making them less affordable for small and marginal farmers. Additionally, these technologies require a high level of technical expertise for operation and maintenance, which can be a barrier in rural farming communities. Field variability, including uneven terrain and diverse cropping patterns,

further complicates the effective deployment of automation systems. Connectivity issues such as weak internet access and unreliable GPS signals in remote areas also hinder their performance. Moreover, not all crops are suitable for robotic harvesting due to differences in size, shape and growth patterns. As a result, research indicates that full-scale automation in agriculture is still evolving and faces significant environmental and technical limitations.

Future of Robotics in Farm Management

The future of agricultural robotics is highly promising, with rapid advancements driving agriculture toward greater automation and intelligence. One of the key emerging trends is the development of fully autonomous farms,

where interconnected robots manage most field operations with minimal human intervention. AI-driven decision systems are expected to further enhance efficiency by enabling machines to predict crop needs and optimize inputs automatically. Swarm robotics is another innovation, where multiple small robots work collaboratively to perform large-scale agricultural tasks more effectively. In addition, climate-smart agriculture will allow robots to adapt to changing weather conditions and reduce risks associated with climate variability. Human-robot collaboration will also become increasingly important, with farmers shifting toward supervisory and decision-making roles while intelligent machines handle field operations.



CONCLUSION

Robotics in harvesting and farm management represents a revolutionary transformation in agriculture, shifting traditional farming practices toward a more precise, efficient, and technology-driven system. By integrating advanced tools such as AI, IoT, machine vision and autonomous systems, modern agriculture is becoming increasingly data-oriented and less dependent on manual labor. These technologies not only improve operational efficiency but also enhance sustainability by optimizing resource use and

reducing environmental impact. In harvesting, robotic systems enable selective and rapid collection of crops with minimal damage, while in farm management they support real-time monitoring, precise input application, and improved decision-making. This integrated approach helps increase productivity, reduce post-harvest losses, and ensure better crop quality, ultimately strengthening farm profitability. Although challenges such as high initial investment, technical complexity, and field variability still exist, continuous advancements in robotics and digital

technologies are steadily addressing these limitations. As innovation progresses, the cost of systems is expected to decline and their adaptability will improve across diverse cropping environments. In the coming decades, robotic systems are likely to become

an essential component of global agriculture, playing a key role in ensuring food security, climate resilience and sustainable food production for a rapidly growing population.