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Agricultural Robots: A step towards Hi-tech Farming

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ABSTRACT
Feeding the populous world is a formidable challenge that requires mechanization of agriculture on a priority basis. For thousands of years, farmers have sought solutions to boost productivity and reduce the number of laborers required per acre. From horse-drawn plows to contemporary innovations like planters, balers, threshers, and harvesters, the focus has always been on executing essential tasks at scale. The evolution of new-age technologies has driven the agricultural sector towards a new paradigm involving digitalization, automation and Artificial Intelligence (AI) in sustainable farm practices. AI, through its machine learning and deep learning capabilities, enhances precision agriculture compared to traditional methods that rely on manpower and human knowledge. Automated equipment and robotics, with their precision in farm operations, not only matches but may even surpass traditional agricultural mechanization, which relies on tractors and engine power. Various autonomous agri-robots are now being employed in agriculture for a wide range of tasks, including sowing, harvesting, monitoring soil conditions, applying fertilizers and pesticides, and herding livestock. The AI-based robots in the agricultural fields use visual imaging techniques to tell the farmer about the crop health, distance between each plant/sapling, moisture and nutrient content of the soil and offering suggestions to combat deficiencies, offering insights on the crop development and the weather forecasts. This helps in reducing the manpower and time consumption, thereby increasing the crop productivity manifold, paving the way towards sustainable agriculture.
Keywords: *Robotics, Agri-bots, Drones, Automation, Artificial Intelligence, Precision agriculture.*

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INTRODUCTION

Agriculture is a time-honoured practice that has been integral to human society since the dawn of communal living. However, this vital sector faces numerous challenges, including lack of accessibility to modern resources, financial constraints and climate-related issues, which hinder productivity and negatively impact livelihoods. These challenges contribute to global food security concerns. According to a report by the Food and Agriculture Organization, we need to produce 60% more food to support a population of 9.3 billion by 2050. Currently, traditional farming methods are placing even greater pressure on the environment and natural resources. Hence, there is an urgent need for modern agricultural techniques that maximize food production with minimal resources, ensuring not only quantity but also nutritional quality for the growing population. The declining workforce and manual involvement in farming practices is not only evident in the developing nations but also shows its impact in the developed countries. Further, the younger generation lack interest in agriculture and explore other career paths. To attract youth to the agricultural sector, high technologies such as drones, sensor-based machines, and robotics must be integrated into farming practices. Up to 86% of Indian farming community predominantly comprises of small to medium farmers, which necessitates the development of advanced machines based on their specific requirements. Thus, robot-based machines and AI technology can significantly ease agricultural tasks and improve efficiency [1]

The application of AI into agricultural industry has introduced new dimensions to the farming sector by enhancing crop health, managing pests and diseases, monitoring soil and water usage, and assessing real-time climatic and growth conditions. Current day precision agriculture is leveraging on AI, machine learning and IoT sensors, which help farmers organize data for valuable insights, such as identifying optimal planting times, selecting appropriate crops, and choosing hybrid seeds to maximize yields [2].

Due to its flexibility, high performance, accuracy, and cost-effectiveness, AI technologies help farmers to overcome numerous challenges like improper soil treatment, disease and pest infestation, big data requirements, low output, and knowledge gap between farmers and technology [3].
In crop production, a variety of optimization models and software tools have been developed for field operations. This progress, alongside advancements in field machinery, offers innovative solutions to many challenges faced by modern farmers. Precision agriculture involves software solutions that incorporate various technologies, including softwares, data analytics, Machine learning, IoT, sensors and robotics (Fig 1). These innovations are transforming modern farming practices through a synergistic approach. The Internet of Things (IoT) describes the network of physical objects "things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. These devices range from ordinary household objects to sophisticated industrial tools. IoT helps in better crop management, better resource management, cost efficient agriculture, improved quality and quantity, crop monitoring and field monitoring etc. can be done. The IoT sensors used in proposed model are air temperature sensor, soil pH sensor, soil moisture sensor, humidity sensor, water volume sensor etc. [4]. Yet another significant issue in crop production is the reliance on labor-intensive tasks, such as harvesting delicate fruits and controlling weeds between rows, which are often difficult for traditional machinery to handle. As a result, there is a growing demand for autonomous tractors and robotic platforms designed for these operations.

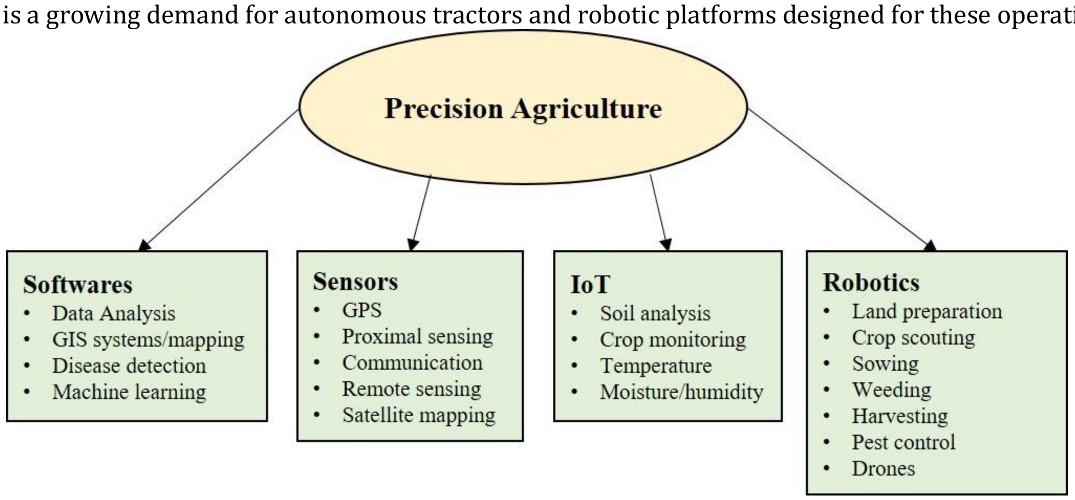

Figure 1. An overview of precision agriculture

Robotic applications in agriculture are rapidly expanding, providing effective solutions with a strong return on investment by replacing human operators for hazardous tasks. Unmanned machines are increasingly employed for activities like dispensing chemicals, spreading manure, and applying fertilizers, highlighting the potential of robotics to enhance productivity and safety. By incorporating advanced technologies such as microcontrollers and sensor arrays, these systems ensure precise task execution and adaptability to varying farming conditions. The use of multiple light, compact autonomous machines as alternatives to traditional large tractors, essentially boost the efficiency and minimize soil compaction. This review emphasizes the transformative potential of robotic solutions in promoting sustainable hi-tech farming and addressing the evolving needs of agriculture.

DEVELOPMENT OF AGRICULTURAL ROBOTS

Robots are becoming more and more technologically advanced, and they are able to carry out increasingly complex tasks that in the past would have been performed by farmworkers. Agricultural robots are automated machines or robotic systems designed to perform various tasks in farming and agricultural settings. They are designed, customised and programmed for performing specific functions in the fields. Traditionally, these robots have helped farmers with repetitive tasks like picking and packing fruits and vegetables or planting seeds—jobs that are becoming harder to fill with human workers due to their monotonous and physically demanding nature, along with low wages. These agricultural robots also termed as '**Agro-bots**' or '**Agri-bots**' are defined as autonomous, mobile, decision-making, mechatronic robots performing crop production operations like preparation of land, crop scouting, sowing seeds, transplanting seedlings, weeding, pest control, and harvesting crops without any human involvement (Fig 2) [5-8].

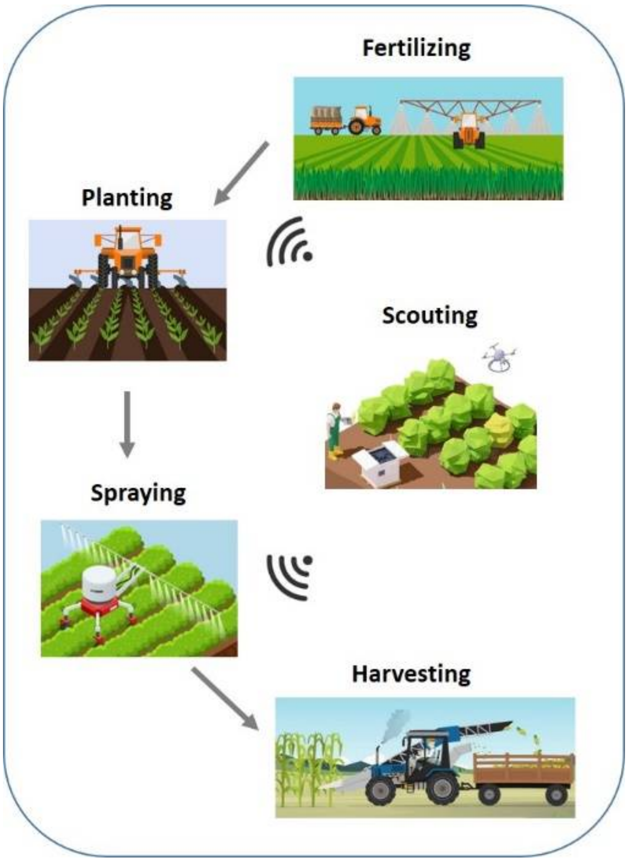

Figure 2. Use of robotics in different field operations.

The primary goal of developing agricultural automation robots is to reduce labour requirements and enhance food quality. These robots address key challenges faced by farmers, including real-time crop quality monitoring, ploughing, seeding, harvesting, spraying, and fruit picking. Currently, agricultural robots are used for phenotyping, monitoring, mapping, crop management, and environmental control in both crop and livestock farming, including aquaculture [9,10]. Research and development have focused on open fields, semi-closed greenhouses, and fully enclosed plant factories, covering tasks such as tilling, grafting, planting, fertilizing, pollination, spraying, and harvesting [11,12]. There are three main types of robotic solutions: airborne, earthbound, and aquiclude [13]. When considering both operation implementation and technical capability, agricultural robots can be categorized into two types: non-selective working robots and selective working robots. Non-selective working robots operate without distinguishing between individual targets. In contrast, selective working robots identify, position, and diagnose specific agricultural targets using machine vision or other sensing technologies to perform selective operations. The varied classification of agricultural robotic systems is vividly explained in Table 1.

Table 1. Classification of agricultural robots.

Based on	Types
Sector applied	Crop farming, livestock and poultry farming, aquaculture
Function	Phenotyping, monitoring, mapping, object handling, environment cleaning
Control	Remote-control, Human-robot collaboration, fully autonomous
Working mode	Selective, non-selective
Mobility	Stationary, Mobile
Space	Aerial, Ground, Aquiclude

To design an ideal agricultural robot, some key factors need to be considered [14]. The main prerequisites are listed as follows:

1. **Modularity**: The robot must be adaptable for various tasks, allowing for easy attachment and removal of tools like arms, sprayers, and weeding equipment.
2. **Cost**: It should be economically feasible for small-scale farmers, as existing robots are often too expensive.

3. **Stability and Reusability**: The robot needs to navigate off-road and over small obstacles smoothly, with settings that allow it to perform multiple functions.
4. **User-Friendly Interface**: A simple interface is essential for small-scale farmers, many of whom may be illiterate.
5. **Compact and Mobile**: The robot should be lightweight and portable, unlike bulky autonomous tractors.
6. **Low Power Consumption**: Given limited power availability in rural areas, the robot should be energy-efficient.

Agricultural robots designed on such factors provide mobility, environmental sensing, and physical sampling. In the field, autonomous robots must calculate the algorithms and seed quantities for planting, adapting to environmental changes without errors. Before deployment, they should assess the future crop production needs, specific tasks and components required and the revenue generated which should ideally exceed the costs of the robot. These autonomous robots can effectively facilitate precision farming.

TYPES OF AGRICULTURAL ROBOTS

Like other industries, agriculture is evolving into a high-tech field that attracts interest from youth and professionals from various sectors. New companies and investors are eager to engage in this area, with many already making strides. Companies are focused on developing robots and drones to enhance agricultural production. Various types of robots are being utilized in agriculture, including soil testing robots, ploughing, seed sowing and seedling planting robots, weed control robots, harvesting and sorting robots for plants and vines, fruit-picking robots, automated grass-harvesting robots, cattle and pasture care robots, etc.

Soil testing robots

Continuous crop growth leads to nutrient depletion in the soil, prompting farmers to apply different fertilizers. However, nutrient levels can vary across fields, impacting seed germination and growth, and resulting in inconsistent production. To address this problem, farmers need to regularly test soil to assess the nutrient levels, which is labour-intensive and challenging. Traditional sampling methods can introduce errors of up to 20% due to changes in depth and location, potentially causing over-application of fertilizers or nutrient shortages in certain areas. An autonomous mobile robot called 'Bonirob' was developed integrating an automatic soil penetrometer, which could operate in two modes, viz. "manual mode," where the user controls it via a remote panel, and "automatic mode," where it functions entirely autonomously [15]. Various other soil monitoring and soil testing robots have been listed in Table 2.

Table 2. Soil testing and monitoring robots

S.No	Robot	Task performed	Sensor used	Photograph	Ref.
1.	Bonirob	Soil monitoring	Penetrometer app		[15]
2.	Smart Core	Soil sampling	RTK GPS, Obstacle detection sensors		[16]
3.	Ground 4-wheeled vehicle	Soil and crop growth monitoring	Stereo camera, GPS, Fluorescence/ IR thermography		[17]

4.	Vehicle mounted Soil texture detector	Soil texture detector	Disc electrode sensor, GPS, Industrial camera		[18]

Ploughing and seed sowing robots

Land preparation and ploughing are the farming practices that involve a large amount of manual labour, machinery and time. Automated ploughing robots offer a promising alternative by the use of smart sensors to determine plant density and cut through the farmlands with precision. The seed beds are prepared by loosening and mixing the topsoil using these robots (Fig 3). Several other autonomous ploughing robots have been developed which first tills the entire field before moving on to ploughing, while simultaneously dispensing seeds side by side. An ultrasonic sensor is used for navigation, continuously transmitting data to the microcontroller [19, 20].

Sowing seeds into larger fields is a laborious process and involves manual involvement for longer durations. However, precision seeding provides numerous benefits, including increased yields, reduced resource waste, improved germination efficiency, and higher productivity. Automated seeding robots utilize GPS and on-board sensors to determine the optimal depth for seed placement and the spacing between seeds, ensuring accurate sowing. Among these robots, the Lumai 5 is particularly notable for its use in wheat precision seeding in countries like China [21]. These robots can operate under various conditions, achieving precision accuracy of up to 93% across different seeding speeds. They consist of three main components: a mobile body with the precision seeding system, a control system that processes sensor signals and operational data, and a sensor system that manages the robot's overall functions. Furthermore, there are seed mapping robots available that record geospatial position of each seed using sensors. The seeding Agribots operate through the interaction of several mechanisms: a hole digging system, a seed dispensing system, a hole filling system, a drip irrigation system, a control system with sensors, and a drive system [22]. Such mechanized robots aid in tremendous time saving and increased efficiency in sowing seeds at regularly spaced holes.

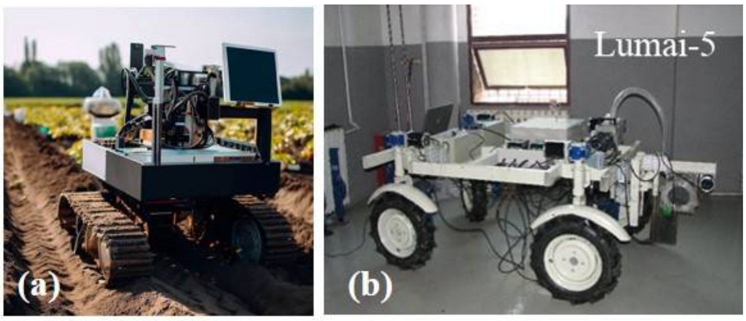

Figure 3. (a) Automated ploughing robot, (b) Lumai-5, seed sowing robot

Weeding robots

In conventional farming, various effective weed control measures have been explored, including agricultural control, plant quarantine, hoe weeding, biological weeding, and chemical weeding [23]. However, traditional weeding methods are often labor-intensive and expensive, while the overuse of agricultural chemicals has led to significant environmental pollution and public health issues. Researchers and developers are increasingly focusing on weeding robots due to their significant advantages in reducing labour intensity, minimizing resource waste, and enhancing efficiency. The key components of these robots include visual navigation, weed detection, and targeted weeding. They utilize image pre-processing, navigation line extraction, segmentation, and weed recognition, often relying on machine learning (ML) or deep learning (DL) techniques. At their core, these robots employ advanced machine vision systems to distinguish weeds from crops [24]. They utilize cameras and sensors to capture and analyze visual information from the fields, differentiating plants by size, shape, and colour. Once a weed is identified, the robot uses a mechanical tool or herbicide to remove it without damaging the surrounding crops. These robots can improve weeding management by differentiating between weeds and beneficial crops, storing species information, and analysing data [25]. These robots are categorized based on the method of primary weed detection and removal.

- **Vision-Based Mechanical Weeding Robots** employ advanced cameras and sensors with machine vision to differentiate between crops and weeds. Once identified, a mechanical tool—such as a blade or hoe—is used to physically remove the weeds (Fig 4a). This non-chemical approach makes them an environmentally friendly option for organic farming or for farms looking to minimize chemical use.
- **Spraying Weeding Robots** utilize a vision system to identify weeds, but instead of uprooting them, they apply a targeted dose of herbicide directly to the detected weeds using precision spraying mechanisms. This approach significantly reduces chemical usage, making it more environmentally sustainable than traditional indiscriminate spraying methods.
- **Thermal Weeding Robots** use thermal technology to eliminate weeds. After identifying a weed—usually through a vision system—they employ precision lasers or steam to destroy the unwanted plants (Fig 4b). This method serves as an alternative to mechanical removal and herbicides, making it a valuable option in sensitive environments or for tackling resistant weed species.
- **Multispectral Imaging Robots** capture data from both visible and non-visible light, unlike traditional weeding robots that use standard cameras. This allows them to identify plants by their unique spectral signatures, enhancing weed detection accuracy in dense or complex crop environments. Depending on the design, the removal mechanism may be either mechanical or chemical.

Figure 4. (a-c) Mechanical weeding robot; (d,e) Thermal/Laser Weeding robots

Examples of some commercially available weeding robots have been mentioned in Table 3. Although the machine vision technology is effectively used in agriculture to distinguish crops from weeds, positioning it as a valuable tool for precision farming in the future, however, existing machines focused solely on weeding lack flexibility for other tasks. To overcome this limitation, multi-functional smart machines are being developed to automatically remove weeds while enabling variable rate irrigation [26].

Table 3. Some examples of weeding robots

S.No	Robot	Task Performed	Description	Photograph	Ref
1.	Naïo Dino	Weeding	A robot that can carry out specific weeding task & some other tasks like sowing & small tillage		[27]

2.	EcoRobotixEvo	Spraying weeding robot	Solar panel powered autonomous manoeuvring, spot spraying of herbicides		[28]
3.	Ekobot	Mechanical weeding robot	Removes weeds from onion fields		[29]
4.	Nissan robotic ducks	Weeding	These small compact robots remove the weeds & pests in rice fields		[30]

Spraying robots

Plants are protected from pathogens and pests through pesticide spraying, a crucial but hazardous task. Farmers typically use manual sprayers, which they carry on their shoulders, resulting in widespread and over-application of pesticides. This method can release airborne pesticides that enter the farmer's respiratory systems, leading to health issues and even fatalities from prolonged exposure. Robotic sprayers improve pesticide application by utilizing navigation control algorithms for platform movement and efficient trajectory planning to reduce travel distances (Fig 5a). These robots optimize their routes to ensure targeted spraying, minimizing waste and environmental degradation through reduced pesticide use. For instance, the XAG R150 Unmanned Ground Vehicle (Fig 5b) is used for spraying fertilizers & insecticides. This robot can also do various tasks like plant protection & intelligent mowing apart from spraying [31].

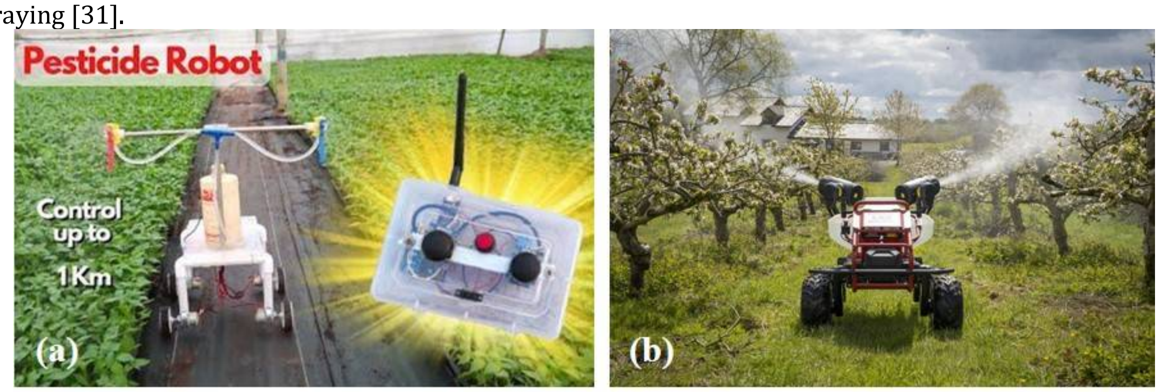

Figure 5. (a) Pesticide spraying robot, (b) XAG R150 Unmanned Ground Vehicle

Planting/seedling robots

As the agricultural landscape evolves, the adaptability and versatility of planting robots are essential for addressing the diverse needs of modern farming. This technology goes beyond merely replacing human labour; it enhances the planting process by filling gaps and making it more efficient, precise, and often more sustainable. More recently, robotic grippers and sensor-based methods have been reported for farming practices [32]. An embedded system has been developed to automate the transplanting of vegetable seedlings in seedling transplanters [33, 34]. The enhanced integration of electronics and computer applications has enabled robotic systems to perform a range of field operations, including transplanting, harvesting, and intercultural practices for both agricultural and horticultural crops [35].

Using a finger type mechanism for extracting the seedlings from soil (Fig 6), high-speed transplanting robots were developed with transplanting frequency of 60-80 seedlings/min [36, 37].

Figure 6. Seedling transplanting robot based on pinching mechanism.

Harvesting robots

Many crops are harvested by hand till date to avoid damage, especially lettuce, cauliflower, broccoli, peppers, eggplants, asparagus, cucumbers, and tomatoes. Harvesting these crops demands significant precision, as fruits and vegetables are often fragile and must be handled carefully to prevent damage, which can directly impact farmers' incomes. To overcome these challenges, robotic harvesters have been designed as per the requirements for fields, orchards and greenhouses. In spite of limitations related to coverage, recognition, and differentiation, most of the harvesting robots are being implemented in agriculture effectively. Significant improvements have been made through vision-based control techniques, including strategies for acquiring visual information, fruit recognition algorithms, and hand-eye coordination methods. Two main challenges in fruit and vegetable harvesting are detecting objects within tree canopies and utilizing existing visual data for accurate picking. Various vision control techniques have been applied to harvesting robots, incorporating visual sensors and machine vision algorithms such as stereo cameras, monocular cameras, multispectral cameras, structured light cameras, image segmentation, object detection, and 3D reconstruction. In this process, the key challenges include maintaining stable recognition in complex backgrounds, managing occlusions from leaves and branches, ensuring consistent recognition under varying lighting conditions, and addressing uncertainties in picking caused by intricate environments.

Harvesting robots are basically autonomous machines designed for harvesting fruits and vegetables in fields, orchards, and greenhouses, equipped with a vision system that includes optical sensors and cameras, to detect fruits and vegetables that are partially or fully concealed by foliage. They assess the position, size, volume, shape, and color of the produce, determining the optimal harvest time regardless of environmental conditions. The optical vision systems are integrated into the robot's "eye" and can be mounted on motorized vehicles equipped with robotic arms, grippers, and cutting systems. The basic components of a harvesting robot are labelled in Figure 7.

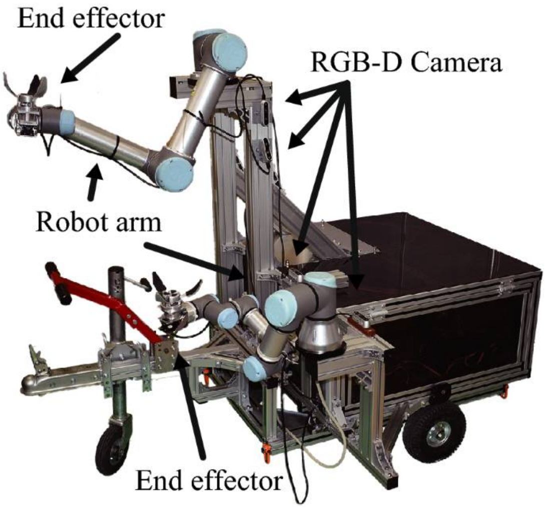

Figure 7. Components of a harvesting robot.

The harvesting robots are designed based on customized requirements of vegetable, fruits or other crops and hence utilize combinations of grasping and cutting, vacuum suction and plucking, twisting and pulling, and shaking and collecting. Grasping and cutting mechanisms are usually applied to crops like strawberry, tomato, lettuce, sweet pepper, citrus, grapes, eggplant, asparagus, and pumpkin. The strawberry plucking robots (Agrobot E series) use robotic vision with two colour CCD cameras and a laser sensor to identify the ripe strawberries from the raw ones and gently plucks the fruit from its stem using a flexible robotic arm to collect it in a bin which are then sorted according to shape and size [38]. Often, soft sponges are incorporated inside the gripper to prevent the ripe berries from damage (Fig 8b). For example, the robot Rubion developed by Octinion, picks almost 795 lbs of strawberries in a day as compared to 110 lbs by human pickers (Fig 8a). The sweet pepper harvesting robot (Harvey platform) utilizes a vibrating blade to cut the fruit stem (Fig 8c) [39], while a lettuce harvesting robot (Vege bot) contains two pneumatic actuators- one to cut the lettuce stem and other to grasp the lettuce head to prevent damage (Fig 8d) [40]. Citrus harvesting robots use grasp and bite method (Fig 8e) [41]. For harvesting pumpkins, the end effector is equipped with five fingers to grip the pumpkin following which a 60 ∘ angled blade cuts the stem (Fig 8f) [42].

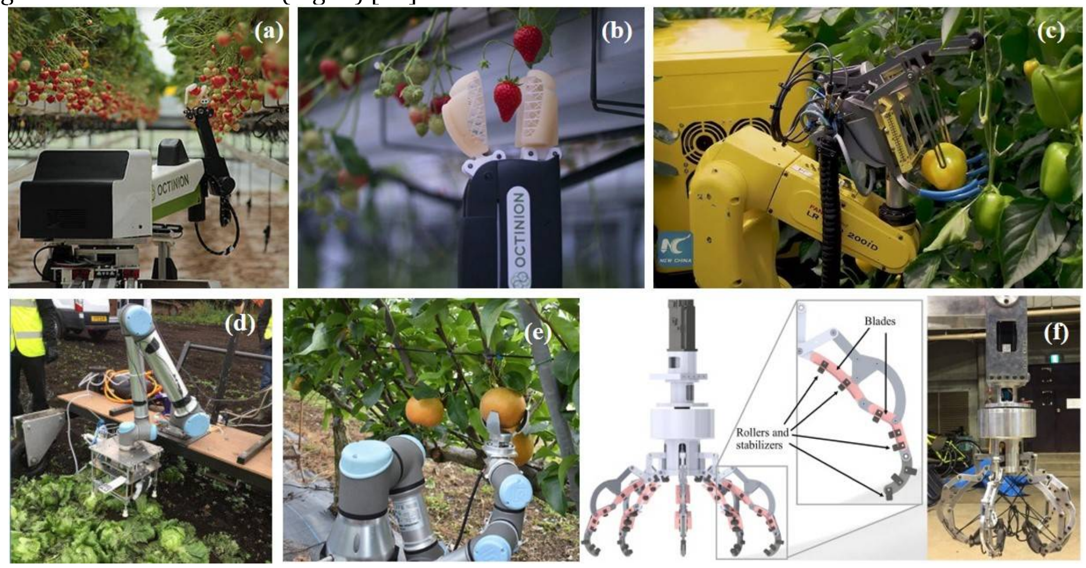

Figure 8. Robotic harvesters for (a) strawberry, (b) cushioned end effector, (c) sweet pepper, (d) lettuce, (e) citrus, and (f) pumpkin (5-fingered end effector)

Vacuum suction and plucking methods are used in harvesting cotton and apples. The end effector is fitted with a soft silicone suction cup at the front end which holds the fruit while rotation and cutting releases the fruit without getting damaged (Fig 9a) [43, 44]. Apple harvesting involves twisting and pulling mechanism, utilizing an end effector made up of three highly compliant pneumatic actuators arranged around a flexible, soft palm that supports the apple against the actuators (Fig 9b). Specialized robots like Amaran agro-bot (Fig 10) are designed to climb and harvest coconuts [45].

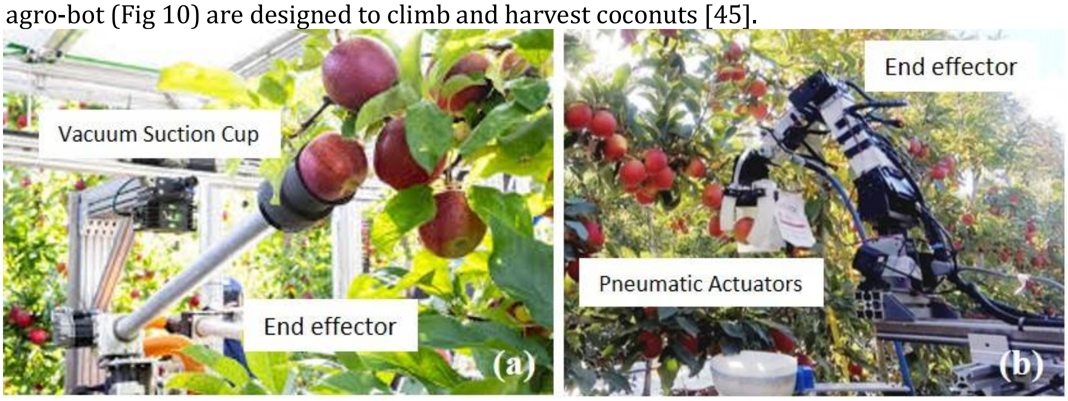

Figure 9. Apple harvesting robots using (a) vacuum suction and plucking, and (b) twisting and pulling mechanisms.

Figure 10. Coconut harvesting robot, Amaran [45].

Eventually harvesting machines have also been established for crops such as wheat, soybeans, and corn and other cereal crops [46]. A harvesting robot substantially increases the productivity and yield preventing damage to the fruits and vegetables and greatly reduces the time and effort of a farmer.

Multipurpose agricultural robots

Yet another trend in Agribot technology, is the emergence of robotic systems capable of performing multiple tasks—such as planting, fertilizing, and spraying—in a single pass. These multi-tasking robots enhance efficiency and reduce the need for various pieces of equipment and human labor. Based on this, many multipurpose agricultural robots have been designed that can handle tasks from seedbed preparation to harvesting. These can operate efficiently with additional attachments and can be controlled via remote or mobile app. These robots leverage IoT to map fields and analyze soil parameters such as moisture, porosity, and luminosity. They also measure the distance between seeds and ensure accurate seed placement. Additionally, these robots collect data on soil conditions and weather, storing it in connected apps. Benefits include remote control, hands-free operation, data collection and analysis, reduced labor, and increased efficiency [47]. Utilizing such multipurpose robots (Table 4) in agriculture offers several benefits, providing a cost-effective solution for farmers to meet the growing demand for affordable production.

Table 2. Some multipurpose agricultural robots.

S.No	Name of the Robot	Task Performed	Description	Photograph	Ref.
1.	Terrasentia	Imaging	A compact robot that collects the under-canopy data using two fish eye vision cameras on the sides.		[48]
2.	Agrointelli-Robotti	Multipurpose	With the attached standard machinery, it does the ploughing, weeding, & other tasks without the help of a driver.		[49, 50]

3.	Casar	Multipurpose	A fruit robot controlled by remote system that can perform the tasks like spraying, tillage, fertilization, contour cut, harvest & transportation		[51]
4.	Thorvald II platform	Multipurpose	A modified in-field adaptable robot to operate in different production systems—such as tunnels, greenhouses and open fields		[52]
5.	Multi Purpose Agricultural robot	Multipurpose	An intelligent robotic vehicle controlled wirelessly via RF communication used for ploughing, sowing seeds, leveling mud and spraying water		[53]

OTHER APPLICATIONS OF AI AND ROBOTICS IN AGRICULTURE

Agricultural robots find wide applications in agricultural practices due to their variability, flexibility and ease of operation. Specific functions are coordinated and executed using customized robots as discussed earlier. Additionally, Agribots play a role in various other applications like:

- **Crop Disease Detection**: AI is making significant strides in the early detection and diagnosis of crop diseases. Utilizing a neural network trained on a dataset of different images, and smartphone apps connected to imaging drones, disease identification and localized treatment has become impressively easy and accurate. Disease Detection and Spray Pesticide Robots utilize image processing and machine learning to identify leaf diseases, monitor field conditions, and spray pesticides. RobHortic, A remote-controlled field robot that uses proximal sensing to identify pests and diseases in horticultural crops [54]. eAGROBOT is a ground-based agricultural robot that leverages image processing to detect crop diseases, spray pesticides, and provide a comprehensive overview of the farm [55]. Another autonomous agricultural robot designed to detect plant diseases, AGRENOBOT is equipped with a brake system that stops the robot upon detection of a disease [56].
- **Automatic grass cutting:** Landscaping companies often hire labourers to maintain lawns, which accounts for 40-60 percent of maintenance costs. Engine-powered lawn mowers pose safety risks, injuring or paralyzing over 6,000 people annually. In contrast, remote-controlled and autonomous robotic lawn mowers, guided by global navigation satellite systems, are increasingly embraced [57, 58]. Many of these robotic mowers now incorporate GPS, cameras, and ultrasonic sensors to effectively detect and avoid obstacles [59].
- **Livestock management:** A field robot, like the Swagbot, monitors livestock to ensure the health of cattle and grazing space [60, 61]. It improves technology by accurately annotating images of cattle on farms using instance segmentation tools, resulting in high-quality datasets. This supports AI models in effectively recognizing cattle and assessing their health conditions. It autonomously navigates farm roads, collects grass and soil samples, and distributes grass in specific areas—tasks that are typically labor-intensive for farmers. The collected soil samples can be sent to laboratories for testing, helping to analyze soil fertility and improve pasture quality.
- **Predictive Analysis for Crop Yield:** AI-based systems are utilized to analyze weather patterns, identify regional trends, and assess suitable crops for specific areas. This technology has significantly enhanced urban agriculture. For instance, Seedo, an Israeli Agtech company, has developed containers designed for growing crops in urban settings. These chambers target Latin

America and the Caribbean, where over 80% of the population lives in cities. Seedo's chambers use AI algorithms to optimize moisture and light, controlling the internal environment through a hybrid of hydroponics and aeroponics. They can grow fruits, vegetables, flowers, and herbs.

- **Drone-Assisted Aerial Surveillance:** These aerial guardians, equipped with advanced computer vision AI, can detect health issues in crops in real-time and autonomously intervene when needed. Drones with sophisticated AI capabilities now perform spraying tasks with exceptional precision, whether applying protective pesticides or essential nutrients. By conducting detailed real-time analyses of well-labeled agricultural imagery, these drones identify areas requiring attention and adjust their spraying volumes according to the specific needs of the crops, enabling true on-demand fertilization and pest control.
- **Robotic pollinators:** In the absence of Melipona bees, manual pollination must be carried out. Hence, robotic bees have been developed to perform the tasks of actual bees, such as pollinating plants and monitoring the health of beehives (Fig 11a) [62]. They aim to enhance productivity in the agricultural industry, especially as the global bee population becomes increasingly vulnerable. Given the limited time available for pollination, this process needs to be performed quickly. Hiring a larger workforce can be costly, so robotic pollinators have been developed to address this challenge (Fig 11b).

Figure 11. (a) Robotic bee [62] and (b) Robotic pollinator (Pic courtesy: builtin.com, wired.com)

Currently, numerous Agritech companies are emerging, focusing on AI-assisted farming. Initiatives like AI4AI (Artificial Intelligence for Agriculture Innovation) have benefited many farmers in India, such as the Saagu-Baagu project, which helped 7,000 chili farmers in Telangana [63]. Hence, AI-based precision agriculture continues to evolve, supporting farmers worldwide in improving their farming practices.

CONCLUSION

Precision agriculture or hi-tech farming differs from conventional methods by utilizing AI-based tools and robots to enhance efficiency and reduce labour requirements. This approach involves the transmission, storage, and handling of large volumes of data. AI devices gather large volumes of data through 3D imaging and process it to provide actionable insights, necessitating some computer expertise for effective data management. By following AI instructions, productivity has increased while time consumption has decreased. Agricultural robots, created through the collaboration of computer, electrical, and mechanical engineering, assist in various tasks such as seeding, weeding, spraying, harvesting, and post-harvesting. Many robots are inspired by natural methods to reduce labor and time, while being environmentally conscious, as chemical fertilizers and pesticides can harm soil fertility and viability. The once far-fetched dream of integrating AI and robots in agriculture is now a reality. The future Agricultural market with applied AI technology is expected to expand from $1.7 billion to $4.7 billion. Various robotic prototypes, including robotic bees for pollination, are currently in development and testing. While many of these applications remain theoretical, Agritech companies are actively pursuing these innovations to enhance agricultural efficiency. Thus, the use of agricultural robots paves way not only to a sustainable, productive and more efficient hi-tech farming but also offers significant job potentials and research prospects for the future younger generations proficient in updated advanced technologies.

COMPETING INTERESTS

The authors have declared that no competing interest exists.

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