Robotics in Agriculture 4.0

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***Abstract*— In recent decades, Europe has been facing a major workforce shortage. On the other hand, rapid progress is evident across all industry fields, even though the gap between market needs and the application of new technologies still exists. Therefore, to increase the efficiency, profitability, and sustainability of food production, Agriculture 4.0. aims to apply advanced technologies, such as robotics and machine vision, in agricultural production lines. This review aims to present a comparative analysis of the automated monitoring of the life cycle and health of plants and the efficient management of resources through a controlled production process, which is in accordance with the concept of sustainable Agriculture 4.0. This paper presents the analysis of automation and robotization of growing seedlings, including several key steps: planting, watering, fertilizing, detection of parasites, and spraying, and gives an overview of new directions in research and industrial application within Agriculture 4.0.**

***Index Terms*—Agriculture 4.0, robotics, machine learning algorithm, crop health monitoring, automated production.**

I. Introduction

The growth of the population, the development of trade, and the rise of business are among the main causes of the development of new technologies, which cause changes in society and industry and create industrial revolutions. Since the 18th century, humanity has encountered three industrial revolutions through its progress, and fourth industrial revolution has started in the 21st century. Starting with manual production methods, during the first industrial revolution, it was moved to machine production using the power of steam and water. The first industrial revolution is related to the 18th and 19th centuries, it had the greatest effect on the production of textiles, the iron industry, agriculture, and mining, and the social effects were felt in the strengthening of the middle class. The rapid transmission of electrical energy, the rapid circulation of goods with the invention of the railway, and information with the invention of the telegraph network led to the second industrial revolution in the 19th and early 20th centuries. Electrification enabled the development of modern production lines in factories, which led to a period of great economic growth with increased productivity. The third industrial revolution, known as the digital revolution, began with the development of the computer and its applications and is related to the second half of the 20th century. The widespread use of computer and communication technologies created the automation of the production line, which accelerated the production process. The need for manpower has become less and less.

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The fourth industrial revolution, Industry 4.0, represents a new era of technical development and social patterns related to the 21st century and conditioned by the processes of digitization and automation. The main characteristic of the fourth industrial revolution is the synergy of modern smart technology, large-scale machine-to-machine communication, artificial intelligence, the internet of things, and robotics. This integration results in increased automation, improved communication and self-monitoring, and the use of smart machines that can analyze and diagnose problems without the need for human intervention.

Like all branches of industry, agriculture also felt the impact of every industrial revolution, starting with manual tillage and food production through the use of machines and automated cultivation and production processes. Despite the increase in agricultural productivity, past agricultural revolutions left many problems unsolved. For example, the Green Revolution had unintended consequences, such as damage to the environment. Therefore, the food industry requires more and more safety and transparency in the food production process. The goal of Agriculture 4.0 is to unify all parts of the agricultural value chain, including off-farm segments. This differs from the first three agricultural revolutions, which primarily affected production techniques and farm technologies. Agriculture 4.0 encompasses a wide range of technologies, most of which have multiple applications along the agricultural value chain. These technologies include loud computing and big data analysis tools, artificial intelligence, the Internet of Things, digital platforms, advanced imaging processing technologies, automated machinery, and agricultural robots. The benefits of Agriculture 4.0 are multiple:

1. Increased efficiency: Agriculture 4.0 enables farmers to optimize their operations through real-time monitoring and data-driven decision-making. This helps to reduce resource waste, minimize costs, and increase overall farm productivity.
2. Enhanced Crop Management: With Agriculture 4.0 technologies, farmers can monitor crop growth and health in real-time, leading to better crop management practices. AI algorithms can analyze data from various sources, including weather patterns, soil conditions, and historical crop data, to provide insights on optimal planting times, crop varieties, and disease management strategies. This can result in higher crop yields, improved crop quality, and reduced losses due to pests and diseases.
3. Sustainable Agriculture: Agriculture 4.0 offers opportunities for more sustainable farming practices.

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By using IoT devices to monitor and manage resources such as water, fertilizers, and pesticides, farmers can use them more efficiently, minimizing environmental impact and reducing chemical runoff.

4. Data-Driven Decision Making: Agriculture 4.0 generates vast amounts of data from various sources, such as sensors, drones, satellites, and farm management software. Analyzing this data can provide valuable insights and enable data-driven decision-making. Farmers can use this data to optimize farm operations, predict yield outcomes, plan for weather events, and manage risks. This can result in better farm management, increased profitability, and reduced uncertainty.
5. Access to Information and Market Opportunities: Agriculture 4.0 can also provide farmers with access to information and market opportunities that were previously unavailable. Digital platforms and marketplaces can connect farmers with buyers, helping them to sell their products at better prices and access new markets. Additionally, digital tools and information-sharing platforms can provide farmers with access to best practices, weather forecasts, and market trends, helping them make informed decisions and improve their overall competitiveness.
6. Automation and robotization of the production process: Agriculture 4.0. can provide an easy way of cultivation, care, and processing in agriculture using robotics. The tendency to use robots in agriculture is growing, and they are most often used in the processes of harvesting, watering, planting seeds, removing weeds... In this way, human efforts in food production can be reduced, and the consequences of a labor shortage can be eliminated.

In summary, Agriculture 4.0 has the potential to revolutionize traditional farming practices by leveraging advanced technologies to optimize resource management, improve crop and livestock management, enable data-driven decision-making, and provide access to new markets and information. This can result in increased efficiency, sustainability, and profitability for farmers, while contributing to food security and environmental sustainability.

The aim of this paper is to review innovative solutions to the existing robotic systems that have found application in Agriculture 4.0. The paper will give an overview of the achievements so far in the process of plant production and care, which includes several steps: tilling the soil, sowing, watering, fertilizing, spraying, and disease detection.

II. Materials and Methods

The materials used as sources of data sources for this review article are obtained from Google Scholar, Scopus, and IEEE Xplore databases. Since Agriculture 4.0 primarily represents the application of existing scientific discoveries, the search for innovative solutions that apply robotic systems in agriculture was carried out by searching patents through the Espacenet Patent search site and Google Patents. In general, all robots are classified according to the following criteria: soil preparation robots, seeding robots, watering robots, fertilizing robots, parasite detection and spraying robots, picking robots, and plant monitoring through sensors. These evaluation criteria were chosen to highlight the main technologies used for the production and care of seedlings across all agricultural tasks represented at the Figure 1.

Fig. 1. Agricultural cycle - the cycle of plant production and care [25]

A. Robotic Applications in Agriculture for Land Preparation before Planting

Preparing the land before planting is one of the first agricultural tasks to be performed. Good preparation and analysis of the land increase its productivity and thus yield better harvest results. In closed conditions such as greenhouses, soil quality can be strictly controlled by purchasing already prepared land intended for the plant being planted. On the other hand, land quality can be improved by applying fertilizers and controlling atmospheric conditions. Therefore, the robot for land processing and analysis is primarily used on open plantations. Robots that work outdoors must be very adaptable to uneven terrain, so mobile platforms on four wheels are most often used. Some of the autonomous tractors that can move autonomously on rough terrain carrying plowing, tilling, and digging equipment are produced by companies like John Deere, AGCO, and Blue River Technology. In the greenhouses, automated lines are mainly used on already prepared land in the process of filling and mechanical processing (fine shredding).

The process of automated matrix plant cultivation is presented in the patent [1]. The process consists of several basins in which planting containers float. Using a hydraulic pushing system, the planting containers are moved from the soil filling workshop to the seeding workshop. The process can also be carried out in reverse. The plant factory does not require special environmental conditions, has a high level of

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automation, improves plant production efficiency, and can achieve better economic benefits.

Automated land processing and open-field sowing system using a wheeled robot with a robotic arm are proposed in a patent [2]. The system consists of a walking mechanism and two robotic arms. The first robotic arm is used for land processing (making holes) and planting, while the second one is for watering the plants.

The process of digging and shredding soil in an open and uneven area using multiple robotic arms is presented in the patent [3]. This system consists of 3 robotic arms and a movable part to which the arms are attached. One robotic arm performs rough digging of the soil using a tool similar to a hoe, while the second arm shreds the excavated soil. The third arm levels the shredded soil according to the necessary characteristics of the soil for plant cultivation.

A system for recording land using two depth cameras, detecting weeds and foreign objects on the ground and removing them, as well as a mini-tiller for soil cultivation has been proposed in the patent [4]. The system consists of a wheeled mobile platform with a robotic arm that has multiple integrated end devices (claws) for weed and object removal and mini-tiller soil cultivation. This system is suitable for various complex terrain conditions, can be applied for all-time operations 24/7, has a high load capacity, strong flexibility, and a high degree of freedom.

B. Robotic Applications in Agriculture for Sowing and Planting

The use of robotic applications in agriculture for sowing and planting can lead to more efficient and cost-effective farming practices. By reducing the need for manual labor, these technologies can also help to address labor shortages and reduce the physical strain on farmers. Autonomous seeding robots are designed to navigate fields, plant seeds, and then move to the next area. They can be programmed to operate in a straight line or in a specific pattern to optimize planting density. These robots are equipped with sensors that enable them to detect obstacles, soil quality, and moisture levels, ensuring that the seeds are planted at the right depth.

Robotic planters are similar to autonomous seeding robots, but they are designed to plant seedlings instead of seeds. These robots can plant seedlings at a faster rate than humans and with more precision, ensuring that each seedling is planted at the correct depth and spacing.

A robotic seeder that uses artificial intelligence and a robotic arm is presented in a patent [5]. The whole system consists of a stand on which a robotic arm is attached, conveyor belts and a visual system. The visual system records the position of the container for seedlings, and the robotic arms, equipped with suction heads, perform the sowing operations. The use of vacuum suction cups made of elastic material for the suction cup heads effectively avoids the clogging problem, facilitating actual use. The use of vacuum suction cups made of elastic material for the suction cup heads effectively avoids the clogging problem, facilitating actual use.

The patent [6] presents the invention of an automated seedling transplantation system for greenhouse pots designed for industrial seedling production. The automated system for transplanting seedlings in greenhouses is a sophisticated system that automates the process of supplementing and transplanting seedlings into pots. It reduces labor costs, increases efficiency, and is ideal for industrial seedling production. The system includes a stand, an image detection device, a seedling supplement device, a device for transplanting seedlings into pots, and a transport device. The process begins with the transport device moving the tray with seedlings while the camera detects the location of missing seedlings and inferior holes for the seedlings on the tray. When the detection is complete, the tray is moved via the transport device to the seedling supplement device. A mechanical arm for supplementing seedlings begins the operation of removing and supplementing seedlings under the guidance of image detection information. When the operation of supplementing seedlings is complete, the tray is transported to the device for transplanting seedlings into pots via the transport device. After that, the mechanical arm performs the transplantation of the seedling into the target pot.

In the patent [7], precise operation is described for an agricultural robot that is designed for use in the field of agricultural production. It has a high-load, four-wheel drive frame that supports a control box and a multifunctional holder. The multifunctional holder has a hanging bracket, a mechanical arm, a tool head, and a camera. The tool head and the camera are installed at the tail end of the mechanical arm, and the tool head can be replaced as required. The material conveying pipe is connected to the material box, and the camera communicates with the control box via a bus. This robot is small in size and can automatically perform fertilization, seeding, and chemical-free weeding tasks. This robot can help increase efficiency, reduce labor costs, and improve yields while minimizing the need for chemical pesticides and fertilizers.

C. Robotic Applications in Agriculture for Watering and Fertilizing

Robotic applications in agriculture have the potential to revolutionize the way watering and fertilizing tasks are carried out in the industry. Watering and fertilization help farmers save time and money while also improving crop yields, minimizing water waste, and reducing chemical use.

Irrigation robots are specialized robots that move through fields, using sensors to detect moisture levels in the soil and apply water as needed. They can be programmed to follow specific watering patterns, ensuring that plants receive the optimal amount of water. Automated watering systems use sensors to detect moisture levels in the soil and automatically turn on and off irrigation systems as needed. They can also be integrated with weather monitoring systems to adjust watering schedules based on changing weather patterns. Robotic sprayers are specialized robots that can be used to spray water or other solutions onto crops. They can be programmed to apply water in specific patterns and at specific times to ensure that plants receive the optimal amount of water. Fertilizer robotic systems can be used for the precise application of fertilizers. These systems use sensors to detect the nutrient levels in the soil, and then apply the appropriate amount of fertilizer to the crops. This can help reduce waste and improve crop yields.

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The patent [8] proposes an intelligent fertilizer application system based on plant cultivation. The system includes housings, a conveying device, an identifying device, a storage device, a planting device, a fertilizer-applying device, positioning devices, a wireless device, and a control center. The housings are designed to be waterproof, and there are multiple housings in the system. The conveying device includes a conveying motor, a conveying rail, a conveying roller, and a fixing device. The identifying device includes a camera, a soil detector, and a soil humidity sensor. The storage device includes a seed storage cabin, a seed channel, a fertilizer storage cabin, a fertilizer channel, a matching cabin, and a matching channel. The planting device includes a putting mechanical arm, a plant-placing cabin, an eradicating mechanical arm, and a gripping mechanical arm. The fertilizer-applying device includes a fertilizer applying mechanical arm, a clear water storage cabin, a clear water channel, and a watering mechanical arm. The system also includes positioning devices that are installed in each housing, and their number is consistent with the number of housings. The wireless device is installed in the control center, which is located in a planned position for the central center. Overall, this system is designed to automate the processes of plant cultivation and fertilization. The system uses advanced technology to identify the specific needs of each plant and apply the necessary fertilizer and water to ensure optimal growth. The use of multiple housings and a centralized control center allows for efficient management of large-scale plant cultivation operations.

The invention described in the patent [9] is a crop growth environment data collection control system based on a mobile robot, a space environment sensor, a spraying system, a water and fertilizer system, and a control system. The mobile robot collects data on soil and air parameters within the local growing area. The control system collects data detected by the mobile robot and the space environment sensor, and controls the air conditioning system, light supplement equipment, sprinkler system, and water and fertilizer system to operate according to the needs of the crops in the greenhouse. The sprinkler system adjusts the humidity of the environment and the soil in the greenhouse, while the water-fertilizer system is used to supply the crops with water and fertilizer. This system provides highly precise adaptation of the air and soil environment for crop growth, which can help improve crop yields and reduce waste. It also allows for more efficient and effective use of resources such as water and fertilizer, and can help reduce the environmental impact of agricultural practices.

The invention of a robotic system designed for the efficient management of citrus planting is proposed in the patent [10]. The system consists of a cart body with a workbench, a fertilizing device, an irrigating device, a control device, a mechanical arm, a picking device, and a detection device. The detection device is responsible for collecting images and processing them to identify and determine the location of areas that require fertilizing, irrigating, and picking. This information is transmitted to the control device, which initiates the necessary operations. The system uses a first transfer pump for atomized spraying and a second transfer pump for spray irrigation. The mechanical arm is equipped with a clamping claw and a shearing knife, which are used to pick citrus fruit by clamping and shearing them from their stems. With the implementation of this system, the efficiency of field management is improved, and the processes of fertilizing, irrigating, and picking can be completed in a timely and efficient manner.

In the patent [11], a multi-degree-of-freedom, multifunctional precision fertilization device is presented designed to improve the efficiency and precision of fertilization in crop farming. The device comprises a vehicle body, a vehicle body driving device, a fertilization tank, a hydraulic station, a manipulator, and a working end. The device can be moved automatically and without human intervention. The fertilization tank, hydraulic station, and manipulator are placed on the vehicle body. The end effector is connected to the fertilization tank through a pipeline, where one or more combinations of irrigation water, fertilizer, or pesticide can be stored. The manipulator's end effector comprises a fertilizer applicator and/or a spray head, which are used to apply fertilizer or pesticide accurately. The device can be used to apply fertilizer or pesticide directly to roots, which improves the fertilizer liquid utilization rate and is suitable for crops with different stem heights. It can also be used to apply fertilization during different growth stages.

D. Robotic Applications in Agriculture for Parasite Detection and Spraying

After sowing, it is important to monitor the growth of the plants regularly to ensure that they grow healthy and free of any diseases or pests. This includes watching for any signs of plant stress or damage, such as wilting, yellowing, or discoloration of leaves, or the appearance of plant parasites, and taking appropriate action to address the problem. In addition to these measures, it is important to use environmentally friendly and sustainable methods of pest and disease control, such as integrated pest management, which involves using a combination of cultural, biological, and chemical controls to manage pest populations and minimize the use of harmful pesticides. Agriculture 4.0 aims to apply the latest software tools for recognizing and detecting changes in plants using machine learning algorithms. The goal is to train algorithms based on a large dataset of images of infected or damaged plants that will recognize the cause of the damage and provide feedback to the farmer about the health of the plant.

The paper [12] presents a developed robotic system for detecting ashtrays and tomato spotted wilt virus disease in greenhouses, using a 6 degrees of freedom (DoF) manipulator arm, RGB camera, and laser distance sensor (DT35, Sick). The RGB camera and laser sensor are mounted on the final actuator of the manipulator for capturing images from different angles and avoiding collisions with the facility. Images are used in the disease detection process, using principal component analysis and variation coefficient analysis. The system achieves an accuracy rate of 64% for the classification process of plants with powdery mildew disease in the early stage of evolution, and up to 90% for tomato spotted wilt virus, allowing for precise detection of diseases in the initial stage. The mobile robot eAGROBOT [13] was also

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used for identifying pests in cotton and peanut crops, using artificial intelligence algorithms such as artificial neural networks and K-means on RGB camera images of the crops in the early stage of planting (period of disease occurrence such as leaf spot and anthracnose). The robot achieved an accuracy rate of 83-96% for disease identification in normal images and 89% for wide images.

The agricultural multifunctional intelligent robot described in the patent [14] is a device designed to automate various agricultural operations, such as weeding, insect-killing, fertilization, and soil analysis. The device consists of a walking device and a working platform, which is situated above the walking device. The walking device moves along a bed of plants, and the working platform is located above at least one row of seedlings. The working platform of the robot is equipped with an insect suction device, a photoelectric scanner, an inter-row weeder, an underground fertilizer applicator, an inter-seedling intelligent weeder, a sprayer, an insect-catching manipulator, and a soil analysis detector. These devices enable the robot to perform a wide range of agricultural tasks automatically and efficiently.

The patent [15] presents a utility model of a robot designed for agricultural pesticide spraying. It consists of a pesticide box, a robot vehicle body, and a camera module. The pesticide box is used for storing the pesticide liquid that needs to be sprayed on the crops. The camera module is installed above the robot vehicle body and is used for acquiring image information of the crops and transmitting images to the main controller. The camera modules are arranged in front of the robot body in a bilateral symmetry mode, which ensures a wider field of view and more accurate image acquisition. The pesticide sprayer is used for spraying pesticides on different crops or different parts of the same kind of crop. This robot provides an efficient and automated solution for agricultural pesticide spraying. It can cover large areas quickly, accurately identify crops, and spray pesticides precisely where needed, thereby reducing the amount of pesticide used and increasing crop yields.

The pesticide spraying robot for agriculture presented in the patent [16] is designed to work in complex and changeable farmland environments. The robot body and the medicine container are connected through a threaded mounting frame, which provides a stable and secure connection. The connecting frames and flight module enable the robot to fly over uneven ground and uneven soil firmness, making it easier to work in complex farmland environments. The adjusting spray device ensures that the pesticide is sprayed evenly and accurately, and the supply pump adjusts the settings of the spraying device according to the requirements of the farmland environment. The top cover and top cover mounting spiral disk protect the robot body and the medicine container from damage and provide easy access for maintenance.

E. Robotic Applications in Agriculture for Picking and Harvesting

Robotic applications in agriculture for picking have become increasingly popular in recent years due to the rising demand for efficient and cost-effective solutions to labor shortages and food production. Here are some of the most common robotic applications for picking in agriculture. Fruit picking robots use cameras and sensors to locate and identify ripe fruit on trees and pick them up without damaging them. They are especially useful for crops such as apples, oranges, and grapes. Vegetable picking robots are designed to pick a variety of vegetables, such as tomatoes, cucumbers, and peppers, using robotic arms equipped with specialized grippers. Harvesting robots are designed to harvest crops such as lettuce, strawberries, and other crops that are close to the ground. They use cameras and sensors to locate and pick the ripest crops without damaging them.

The agricultural robot system described in patent [17] is an innovative solution for automating and optimizing various agricultural processes such as harvesting, pruning, destroying, weeding, and measuring agricultural crops. The agricultural robot consists of robotic arms connected to a self-propelled automated platform. The arm may be configured or coupled to a device configured to harvest, pick, prune, cull, thin, spray, weed, take samples, or perform any other agricultural task. By using autonomous and semi-autonomous robots equipped with cameras and other tools, farmers can improve the efficiency and accuracy of their tasks. One of the key advantages of this system is that the robots can identify and locate fruit, points on the vine for pruning, or other agricultural parameters using machine vision. This reduces the need for manual labor and can help ensure that crops are harvested or pruned at the optimal time for maximum yield. Another advantage is that robots can be used to map plant locations and create an action plan for each individual plant based on its size, fruit, and other parameters. This allows farmers to optimize their resources and ensure that each plant is treated according to its individual needs.

The patent [18] illustrates a mobile working station that includes an agricultural vehicle, such as a tractor, with an attached platform connected to the agricultural vehicle via a carrier used for mounting a loader, and robotic arms attached to the platform. The robotic arm can carry various devices that can be swapped out depending on the specific task. For example, the arm can be equipped with a claw-like tool that can be used for grasping plants or produce growing on trees. This would be particularly useful for tasks such as pruning, harvesting, or even thinning. The range of objects that can be manipulated by the robotic arm is quite wide and can include loose materials, soil, plants, fruit, tools, and even sensors or instruments for measuring the surrounding environment. This suggests that the working station could be used for a range of different applications, such as precision agriculture, environmental monitoring, or even construction or manufacturing. By allowing users to swap out equipment as needed, the station can be adapted to perform tasks that would be difficult or impossible using traditional manual labor.

The invention presented in the patent [19] is a system and method designed for robotic harvesting of agricultural crops. In order to automate the harvesting of fresh fruits and vegetables, it is proposed to use a robot that contains a machine vision system with semiconductor digital cameras for locating and identifying fruits on each tree and a fruit picking attachment a robotic harvesting system for agricultural crops, which includes a self-propelled platform with one or more

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articulated picking arms, each equipped with cameras and a fruit picking attachment. Cameras on the robot are mounted in protective housings, allowing them to be moved into the plant canopy if needed to map fruit locations from within the canopy. The robot first maps the field using a machine vision system containing rugged solid-state digital cameras. Once the mapping is complete, the robot plans and executes an efficient harvesting plan, which can be generated by the scout robot, the harvesting robot, or a server. The system is designed to communicate wirelessly between its different components.

The described invention in the patent [20] is a robotic fruit picking system that is designed to automate the fruit picking process. The system includes an autonomous robot that has a positioning subsystem that allows it to move autonomously around the orchard or farm. The robot also includes one or more picking arms and picking heads that are used to either cut the stem or branch for a specific fruit or pluck that fruit from the tree. To enable accurate and efficient fruit picking, the robot is equipped with a computer vision guidance system that uses machine learning techniques to analyze images of the fruit. In addition, a quality control subsystem is used to monitor the quality of the fruit and grade it according to size and quality. The robot also includes a storage subsystem that is used to store the picked fruit in containers for storage or transportation. The fruit can also be stored in punnets for retail, making it easier for consumers to purchase fresh fruit.

F. Robotic Applications in Agriculture for Plant Monitoring through Sensors

Robotic applications in agriculture for plant monitoring through sensors involve using robots equipped with various sensors to collect data and monitor the health of crops. These sensors can include cameras, multispectral sensors, light detection and ranging sensors, and GPS sensors, among others. The data collected by the sensors can be used to determine the health of the plants, detect any pests or diseases, and determine the water and nutrient requirements of the crops.

The invention described in the patent [21] is a fully automatic, unattended agricultural robot designed for use in greenhouses. The system consists of a wireless communication module, a sensor data acquisition module, an image recognition module, and an operation module. The robot is designed to enter the greenhouse on a regular basis and collect environmental data on plant growth using the sensor module, as well as plant growth data using the image acquisition module. The collected data is then transmitted to a terminal for analysis. Based on the analyzed data the robot gives instructions from the mechanical arm about future actions. This allows the robot to perform specific tasks, such as watering or fertilizing, with precision and low error rates. The use of sensors and image recognition technology ensures that the robot can accurately analyze the environment and current state of the plants, allowing for precise operation.

The greenhouse crop growth inspection robot presented in the patent [22] is designed to inspect and monitor crop growth in greenhouses. The robot is designed to travel on greenhouse rails and can acquire and monitor plant growth microenvironment information in the greenhouse in real-time through sensors carried by the robot. The robot's arm and unique detecting mechanism enable it to perform various inspection and monitoring functions, while the intelligent and smart terminal mechanism at the end of the arm enables the robot to transmit the collected data to a central control system. The use of the greenhouse crop growth inspection robot can significantly reduce the need for manpower and material resources while improving greenhouse crop management efficiency.

In the patent [23], methods are described that involve the use of penetrating radiation such as x-rays to scan across living plants in field conditions. Compton scatter is detected from the plant and processed to derive various characteristics of the plant, such as its water content, root structure, branch structure, xylem size, fruit size, fruit shape, fruit aggregate volume, cluster size and shape, fruit maturity, and an image of a part of the plant. The same technique can also be used to measure groundwater content. Moreover, Compton backscatter can be used to guide a robotic gripper to grasp a portion of the plant, such as for harvesting fruit. These methods can provide a non-invasive and accurate way to characterize living plants and can be used in various applications related to agriculture and plant biology.

In the patent [24], a multifunctional intelligent soil sampling device is presented, which includes a crawler-type cart, a housing, a fertilizer box body, and a sampling device. The sampling device uses a sampling probe attached to a robotic arm. The data recorded with the sampling probe is processed by artificial intelligence algorithms and provides the user with information about possible future actions. The sampling device can work in multiple cycles and perform multiple detections. It can also be programmed to operate automatically, reducing the need for staff and improving efficiency.

III. Conclusion

Based on the analysis of the patents presented in this paper, conclusions can be drawn about the advantages and disadvantages of using robots with robotic arm in agriculture.

1. For the task of land preparation, robots have found application in small spaces and greenhouses, while tractors of the new generation are still used for soil cultivation in open spaces. Traditional tillage of the land using tractors results in a high rate of soil compaction and unadaptability to different terrains and the appearance of obstacles. The application of robotic systems, whose locomotion is not based on wheels, that have vision systems for recognizing obstacles and control systems that enable the adaptation of robotic movement to different terrains would give great progress in agriculture. Therefore, this aspect of the development of robotics in agriculture has great potential.
2. For the sawing and planting task the application of robotics has led to more efficient and profitable agricultural practices. By reducing the need for manual labor, these technologies have helped address labor shortages and reduce the physical burden on farmers. Also, the process of automated sowing has reduced the loss of resources (meaning seeds), which

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price can be very high depending on the variety of plants.

3. The use of sensors and robotic systems for irrigation and fertilization tasks is already yielding results. By using sensors to detect soil moisture levels and nutrient levels, precise and accurate plant care has led to higher yields. Robotic mechanisms combined with sensors have defined new patterns for watering and fertilization plants that are in line with the current soil conditions, plant life stages, and weather conditions. By monitoring the plant life cycle and environmental conditions and treating the plants in a controlled manner using robotics, crop yields have improved, and chemical waste has been reduced.
4. Detection of parasites and spraying represent one of the key challenges of Agriculture 4.0. Parasites and other unwanted plants pose a significant cost for the agricultural industry. Many parasites can be treated with pesticides, but for various reasons, there is an increasing resistance to their use. Pesticides can be expensive, especially when applied in a non-targeted, comprehensive manner. Pesticides are also increasingly under environmental control due to their role in contaminating groundwater and other water sources. There is a perception that chemicals used in agriculture can be harmful to human health due to prolonged exposure, putting pressure on growers to stop using them. Detection of parasites at all stages of plant development using robotics and machine learning is the latest trend in Agriculture 4.0. This area represents the greatest potential for improving agriculture because it enables daily monitoring of plants and analysis of their health status. Based on the plant growth findings (degree of infection, appearance of plants...), existing machine learning algorithms can generate reliable data on the type of parasites and the degree of infection. Robotic applications in agriculture for plant monitoring through sensors have the potential to significantly increase crop yields and reduce the use of pesticides and other harmful chemicals.
5. The processes of picking and harvesting are the most challenging steps in agricultural production and takes up the most time in the entire production chain. Harvesting fruits and vegetables requires special adaptation for each type of plant due to its physical characteristics. In this area of agriculture, robotic systems have found the most application and are seen as having great potential because harvesting is a very difficult and repetitive task. Various systems for harvesting fruits specific to each plant have been presented in patents and scientific papers. The aim of robotics for this task is to define universal algorithms for recognizing plant fruits and the degree of fruit ripeness, as well as to define universal mechanisms for harvesting and reaping adapted to different plants.
6. Robotic plant monitoring through sensors has its advantages and disadvantages. Robotic systems can automate data collection more consistently and accurately than manual monitoring, leading to better-informed decisions and improved plant growth. Robotic systems can collect and transmit data in real-time, providing growers with up-to-date information on plant conditions. Robotic systems can be programmed to monitor specific parameters or plant species, allowing growers to tailor their monitoring approach to their specific needs. Finally, robotic systems can be operated remotely, allowing growers to monitor plants from anywhere with an internet connection. However, there are several disadvantages to robotic plant monitoring, including its dependence on technology and its availability. Robotic systems can be expensive to purchase and set up, requiring a significant upfront investment. Robotic systems require specialized knowledge to operate and maintain, which can be a challenge for some growers. Another disadvantage is the need for specific infrastructure and operating conditions. Technical failures can disrupt data collection and potentially harm plant growth if not addressed promptly. Reliance on robotic technology and sensors may not detect certain changes in plants, so human experience and knowledge cannot be fully eliminated from the plant monitoring process. The development of new sensors and the processing of different information related to plant characteristics and their environment represent a challenge in Agriculture 4.0.

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