



Making Agriculture More Intelligent: Progress of Agricultural Robots



Lihua Jiang^{1*} and Yantao Zhang²

¹Suzhou Polytechnic Institute of Agriculture, China

²School of Construction Machinery, Chang'an University, Xi'an, China

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***Corresponding author:** Lihua Jiang, Suzhou Polytechnic Institute of Agriculture, China

Abstract

In this paper, we present a mini review to investigate the development progress of agricultural robots from different perspectives including classification, functionality, and characteristics. The current technical situations and features of grafting robot, picking robot, weeding robot, spraying robot, etc. are introduced with their corresponding application contexts. It is analyzed and concluded that high cost and intellectualization are two major factors that may challenge the popularity of agricultural robots. The development trends of agricultural robots are discussed as well.

Keywords: Agricultural Robot; Intelligent Agriculture; Grafting robot; Picking robot; Weeding robot; Spraying robot.

Introduction

Robotic technology has been wide used in different areas, such as home service, health care, advanced manufacturing, and agricultural industry [1-4]. Agricultural robot is a kind of automation equipment, which takes agricultural products as the operation objects with environmental perception and automated working function [5]. It is the outcome of the rapid development of information technology. The use of agricultural robots can effectively improve production efficiency, reduce the labor burden of farmers and solve the problem of labor shortage. At present, great progress have been made in the field of agricultural robot. Robots adapting to different needs have emerged one after another, such as pesticide spraying robots, grafting robots, picking

robots, harvesting robots [6-9]. The extensive use of agricultural robots is promoting the modern agricultural production to be increasingly intensive and large-scaled.

Classification and Features of Agricultural Robots

Classification of agricultural robots

With the advent of the era of agricultural mechanization, many countries have invested greatly in the research and development of agricultural robots. Various types of robots have appeared frequently [10,11]. According to the different working objects, agricultural robots can be divided into farm robot, fruit and vegetable robot, animal husbandry robot and forest robot. The specific classification is shown in Table 1 [12].

Table 1: Classification of agricultural robots.

Type	Name	Function
Farm Robots	Spraying robot	Depends on the pest identification and control system. Pesticides can be sprayed according to the type and quantity of pests.
	Weeding robot	Based on image processing system and positioning system, weed identification and positioning can be realized. Herbicide selection and spraying can be carried out according to the number and species of weeds.
Fruit and vegetable Robots	Grafting robot	Used for grafting vegetables and fruits and working together with the millimeter diameter embryo.
	Picking robot	Finding and identifying mature fruits through visual sensors
	Sorting robot	Can identify the size of fruit and classify the fruit accordingly.

Animal husbandry Robots	Milk robot	Sensors are used to detect whether cows are suitable for milking, and then to detect nipple position. It can manage the milk quality and quantity in an integrated way [12].
	lumbering robot	Driven by hydraulic system, the manipulator of robot can clean up on the different slopes and terrain.

Features of agricultural robots

Compared with industrial robots, agricultural robots have the following features:

A. Complexity and hard predictability of the operating environment

Crop shape and size always change with time. Crop growth environment is complex and changeable, which brings a severe challenge to the operation ability of robots. This requires agricultural robots to have strong adaptability and achieve high intelligence in visual reasoning and judgment [13-15].

B. Seasonality of operating

Due to the limitation of technical level, most robots only have a single function and work in a certain part of agricultural production, which determines that robotic operation has seasonal characteristics.

C. Particularity of users and prices

On the one hand, agricultural robots are mostly used by farmers with low knowledge level, which requires that agricultural robots must be simple and easy to operate. On the other hand, the overall profit of agricultural products is not high, which determines that the price of agricultural robots cannot be too high [16-18].

Research Status of Agricultural Robots

Grafting robot

The research of automatic grafting equipment is mainly in Japan, South Korea and China. Japan is the first country to develop grafting robots, and then South Korea began to do this research. In 1986, Japan Society for research and development introduced three grafting prototypes, and then Japanese Institute of Mechanization invented a fully automatic vegetable grafting machine. Among them, the most representative type is Jing guan GR800, which was introduced -to the market in October 1993. GR800 uses artificial rootstocks and joints, and its success rate of grafting is about 90% [19-21]. TGR Institute of Japan introduced the grafting machine for melon grafting in 1995.

South Korea began to study the grafting robots in the 1990s. The needle-type automatic grafting machine introduced by South Korean Ideal System Company is their typical product. The machine uses anti-rotation pentagonal ceramic needles to graft. The whole hole tray can provide seedlings. The grafting speed can reach 1200 plants/hour, as shown in Figure 1. Chinese research on grafting robots started relatively late. China Agricultural University is one of the earliest universities in China to study agricultural robots [22-25]. The automatic grafting robot invented by them has been tested in production. The robot solves the problems of tenderness, vulnerability and inconsistent growth of

seedlings, and can be used in cucumbers, watermelons, etc. The grafting robots is shown in Figure 2.

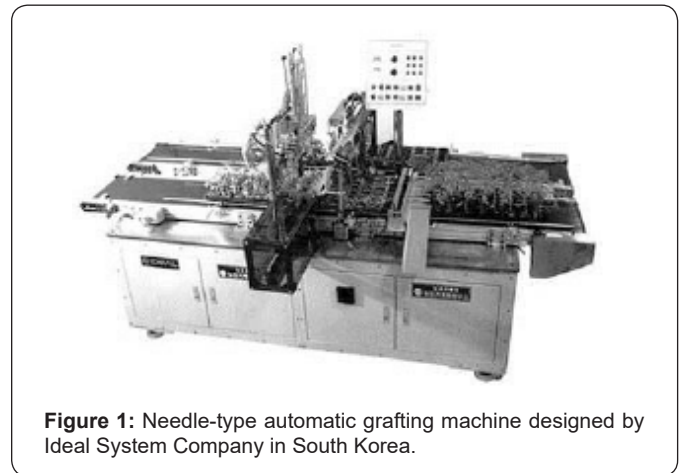


Figure 1: Needle-type automatic grafting machine designed by Ideal System Company in South Korea.



Figure 2: Grafting robot designed by Chinese Agricultural University.

Picking robot

For picking robots, Tomato picking robot was the first one studied. The picking robot developed by Knoto et al. in Japan was the most influential one at that time [26]. The robot mainly consists of three parts: manipulator, vision sensor and mobile mechanism. It separates fruit handle from fruit tree by rotation of wrist joint. In 2004, California Machinery Company launched an automatic Tomato Picking robot, which picked fruit and leaves into the sorting bin, and then selected the fruit through sorting equipment. The separated leaves were broken and sprinkled into the field as fertilizer.

The tomato picking robot developed by Japanese Panasonic Corp is shown in Figure 3. The small lens is used by the robot can shot more than 70 thousand pixels of color images. Firstly, the robot detects mature red tomatoes by image sensors, and then locates the shape and position accurately. When picking, the robot can only pull the vegetable pedicel without damaging the fruit. It

can work continuously at night without human supervision. China began to contact picking robots in the mid-1990s. For a period of time, universities and research institutes in China have been devoting themselves to the research and development of picking robots and has made some achievements. For example, Shenyang

Institute of Automation has invented a tomato picking robot. As shown in Figure 4, its manipulator is a four-fingered structure. The manipulator is equipped with a vacuum suction cup driven by an air pump, which can be used for fruit picking by the adsorption of the suction cup.



Figure 3: Tomato picking robot designed by Panasonic Company in Japan.



Figure 4: Tomato picking robot designed by Shenyang Institute of Automation in China.

Weeding robot

At present, weed removal in the field is a big problem that puzzles farmers. The general weeding methods are artificial weeding and pesticide spraying. These methods not only consume labor but will also cause soil pollution. Researchers at Wageningen University in the Netherlands have designed an automatic weeding robot, which uses a diesel engine as power source and can realize four-wheel steering. The robot uses D-GPS and machine vision to navigate [27]. It can collect the boundary information of farmland in real time and drive along the route of crops independently. The robot also uses advanced vision technology to identify weeds.

Researchers of the Helmstad University in Sweden have developed a weeding robot, which is controlled by a DC servo motor and uses the Ackerman steering on a car as a control mechanism [28]. The robot has two cameras, one of which is a white camera for identifying crop routes and guiding them. The robot travels along the crop and another color camera is used to identify the weeds. It is proved by experiments that the navigation accuracy of

the robot can reach $\pm 2\text{cm}$. as shown in Figure 5. German scientists have developed a weeding robot named BoniRob [29]. As shown in Figure 6, the GPS positioning system of the robot can accurately record the position of weeds and control the accuracy within 2cm. BoniRob can remove 120 weeds in a minute, much faster than manual and medicines.



Figure 5: Weeding robot designed by university of Helmstad in Sweden.



Figure 6: Weeding robot designed by BoniRob in German.

Spraying robot

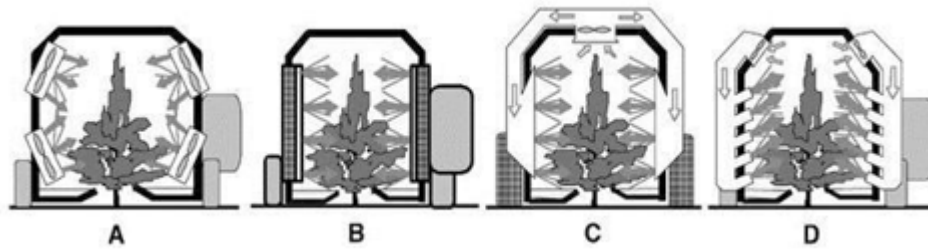


Figure 7: Tunnel type sprayer designed by Holland researchers.

Holland researchers have developed a tunnel type circular sprayer, as shown in Figure 7. The robot has a tunnel shaped cover. When spraying, the cover covers the crops to be sprayed, so that the whole spraying process is carried out in a relatively confined space. This reduces the influence of air flow on droplets. The cover also has a liquid recovery system avoiding the waste of liquid medicine. The robot is mainly used for pest control of crops with lower crowns.

In 1990, Yamamoto launched the first unmanned helicopter for pesticide spraying in the world. As shown in Figure 8, the agricultural unmanned aerial vehicle is efficient, safe and free from terrain restrictions. However, at present, spraying equipment in China are mostly manually-driven, and only a few can self-walk. A tractor sprayer has been developed by Chinese researchers, which combines tractor with sprayer, and realizes indiscriminate spraying, as shown in Figure 9.



Figure 8: Spraying UAV designed by Yamamoto.

Figure 5: W



Figure 9: Sprinkler designed by China researchers.

Other types of agricultural robots

Since the beginning of the 21st century, the research and development of agricultural robots in various countries have developed vigorously. Various agricultural robots adapting to different needs have emerged, such as the seedling-raising robot developed in Boston, USA. It consists of rolling tires, grippers and trays. Workers only need to set location parameters on the touch screen, and the robot can automatically move to the designated working place and effectively shorten the seedling period.

A fruit sorting robot has been developed in the U.K., as shown in Figure 10. The robot is equipped with an electronic image sensor. It can recognize not only the size and shape of the fruit, but also the color of the fruit, and judge the maturity of the fruit. The robot picks the fruit by the giant pincers connected to the vacuum tube to ensure that the fruit is intact. A grazing robot invented by an Australian inventor uses two-dimensional and three-dimensional sensors, and the built-in global positioning system can automatically detect the movement speed of cattle and drive them away, as shown in Figure 11.



Figure 10: Sorting robot designed by Agricultural.



Figure 11: Grazing robot designed by Australia researchers Machinery Institute in British.

Development Trends and Technical Challenges of Agricultural Robots

Although great achievements have been made in the development of agricultural robots so far, there is still a long way to go before the popularization of such robots. By taking the references of robot applications in other fields, some development trends of agricultural robots can be foreseen as follows:

A. Developing more advanced action planning approaches for agricultural robots to improve the agricultural task quality. In some cases, when the robot conducts an assigned agricultural task, it may be inevitable have some negative influences on other targets. For example, when a picking robot picks some apples from the tree, it may produce some harmful actions on thin branches or leaves by its links or end-effector. Therefore, some advanced robot action planning algorithms based on cost functions can be developed to address such issues to improve the agricultural task quality [30].

B. With the increasing complexity of agricultural tasks, traditional agricultural robots cannot finish the tasks effectively and accurately. Therefore, humans need to be involved in such situations, which have similarly happened in manufacturing contexts [31]. Human farmer-agricultural robot collaboration will be a research topic on the way of agricultural robot development.

C. Making the agricultural robot more considerate will be a trend in its development. With the development of agricultural requirements, the agricultural robot will transfer from a machine to be a "human partner" in most of agricultural contexts [32]. Therefore, the intelligence of the agricultural robot such as understanding human intentions will be a large gap to be filled [33].

D. Developing easy-to-use programming approaches for agricultural robots. As we know, it is difficult for the farmer users to program robots with professional expertise when they want to update the robot to new agricultural tasks. Therefore, developing new approaches by integrating multi-modal human information such as natural language or wearable sensing to have farmers program agricultural robots intuitively and to make robot understand or predict human intentions effectively will also be a distinct trend for agricultural robots [34].

The main challenges lie in the following two aspects [35]

The cost is too high: In order to adapt to the complex working environment, agricultural robots generally have complex structures and control systems, which directly leads to the increase of the manufacturing costs. In addition, due seasonal characteristics of these robots, the low working time indirectly leads to the increase of the cost, which makes the current cost-value ratio of agricultural robots far from the market demands.

Lack of intelligence: In order to adapt to the complex agricultural production environment, agricultural robots must have a high level of intelligence. For example, in order to accurately locate crops, agricultural robots must have the functions of automatic path planning, navigation and obstacle avoidance. Although the research in recent years has made breakthroughs in machine vision, artificial intelligence and other aspects, the degree of intelligence of agricultural robots cannot meet the needs of the market.

Conclusion

Great achievements have been made in the development of agricultural robots. Some agricultural production activities can be completed independently by these robots. However, the overall popularization of agricultural robots still faces some challenges. With the development of automation technology, more new techniques will be applied in to this field. In the future, agricultural robots will be developed rapidly in the direction to highly intelligent, comprehensive functions and environmental protection. Agricultural robots will make great contributions to the development of agriculture.

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