Analysis Of Key Technology and Future Development of Fruit Tree Picking Robots

Libo Zhu *
College of Mechanical and Electrical Engineering, Hohai University, Changzhou, China
* Corresponding Author Email: 2161010101@hhu.edu.cn

Abstract. Agricultural robots have been widely used in fields, orchards, facilities, and other agricultural planting. With the development of social economy, there is an increasing demand for fruit among people. However, fruit picking in orchards faces challenges such as labor intensity and shortage. The development of fruit tree picking robots has opened up a new situation for the replacement of manual picking by machines, which overcomes the seasonality and labor problems of manual picking. However, there is a lack of research on the key technologies. Therefore, combined with the literature in recent years, this paper firstly analyzes the research status and key technologies of fruit tree picking robots from the executive system and the perception and decision-making system. The executive system part analyzes the key technologies of fruit tree picking robots in mobile walking and fruit separation from the mobile platform and picking mechanism, and the perception and decision-making system part analyzes the key technologies of fruit tree picking robots in target recognition and system control from the visual system and the analysis and control system. Secondly, the problems of fruit tree picking robots in picking efficiency, picking speed, influencing factors, and generality are analyzed. Finally, the future prospects are made for the existing problems.

Keywords: Fruit tree picking robot; key technology; future development.

1. Introduction

With the gradual development of society, people's demand for quality of life is gradually increasing, especially for fruit consumption. China is the largest country in fruit industry, and the planting and output of fruit trees occupy the first place in the world. According to data from the National Bureau of Statistics of China, labor costs account for 60% of total production costs in fruit production. However, with the acceleration of China's urbanization process, the urbanization rate of permanent residents across the country has increased, which means that the rural population has decreased, and labor costs have increased. In recently, China proposed to reduce the production cost of fruit farmers by realizing the automation and intelligence of orchard machinery and equipment, especially the production cost. Among them, orchard picking is a seasonal and time-consuming production link, and since fruit tree planting in China is mostly concentrated in mountainous and hilly terrain, the difficulty of picking increases [1] Therefore, the use of fruit tree picking robot instead of artificial harvesting is the trend of the times, fruit tree picking robot mechanization, automation, and intelligence have become one of the main research directions of agricultural machinery.

Fruit tree picking robots refer to a class of robots that can visually recognize mature fruit trees and selectively harvest them by using end-effectors [2]. The main structure of the fruit tree picking robot is shown in Figure 1, which is mainly composed of the execution system and the perception and decision system. The execution system includes the mobile platform and the picking mechanism, and the perception and decision system include the vision system and the analysis and control system.

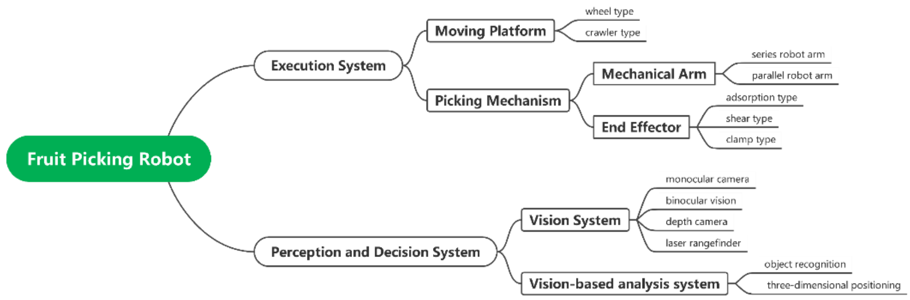

Fig. 1 Main structure of fruit tree picking robot.

The research on fruit tree picking robots is primarily divided into three stages, namely the germination stage, the initial stage and the development stage. In the germination stage, mechanical arm, simple image processing algorithm and moving track are introduced to realize fruit positioning and picking through physical reference. In this stage, fruit recognition rate is low and picking efficiency is low. In the initial stage, with the in-depth study of image processing, deep learning and other algorithms, three-dimensional localization of fruits could be realized, and the recognition rate and picking rate were further improved, but the system was not integrated at this stage and the cost was high. In the development stage, with the development of information technology, the system integration of picking robots can realize the intelligent picking of robots by connecting with big data. At present, research in developing countries is just beginning, in the laboratory and orchard experiment stage, and commercial harvesting has not yet been achieved. The setting of laboratory and orchard scenes is simple, while there are more influencing factors in natural scenes.

Although many people have carried out in-depth research in this field, there is still room for the commercial development of fruit tree picking robots. Therefore, this paper analyzes the key technologies and future development of fruit tree picking robot based on recent references. Chapter 2 analyzes the execution system of fruit tree picking robot, including mobile platform and picking mechanism. Chapter 3 analyzes the perception and decision system of fruit picking robot, including vision system and analysis control system. Chapter 4 puts forward the existing problems of fruit tree picking robot and the future development direction.

2. Execution System

2.1. Moving Platform

The moving platform of the fruit tree picking robot is equivalent to the "foot" of the robot, which can realize the movement of the robot based on the ground, mainly divided into wheel type and track type. The wheel and track structure of the wheel structure can be well attached to the ground to increase the stability of the robot. The wheeled structure is suitable for greenhouse orchards with simple terrain, while the tracked structure has better passability and is suitable for more complex terrain similar to mountain orchards. The greenhouse bell pepper picking robot designed by Arad et al. uses Automatic Guided Vehicle (AGV) vehicle as the chassis, which can pass the ridge road of bell pepper greenhouse along the track and is equipped with scissor elevator for lifting the picking mechanism [3]. A kiwifruit picking robot designed by Hangzhou Chogori Company adopts a tracked chassis, which can realize all-round autonomous walking to adapt to picking in open orchards [4].

2.2. Picking Mechanism

The picking mechanism is divided into mechanical arm and end effector, which is equivalent to the "hand" of the fruit tree picking robot. The role of the mechanical arm is to guide the end effector to reach the target, and the end effector grabs the target. The picking mechanism enables movement in different directions and separation of the stem fruit. This part is a very important part of the fruit tree picking robot, and the design is difficult.

2.2.1 Mechanical arm

The parameters to be considered in the operation of the mechanical arm depend on factors such as the plant's height, system height, fruit quantity, distance and size of the target fruit. Additionally, the payload required for picking the target fruit should also be taken into account. Mechanical arms usually be divided into two types: series mechanical arms and parallel mechanical arms, and most of the current picking robots use series structures. Series mechanical arm systems are usually divided into single arm systems and multi arm systems. For example, Ling et al., developed a tomato harvesting robot with two symmetrically distributed three-degree of freedom robotic arms, featuring one moving pair and two rotating pairs [5].

2.2.2 End effector

For fresh fruit, the integrity of the peel and stem directly affects the selling appearance of the fruit, so the choice of the end effector of the picking robot is very important. There are three main types of end-effectors: cutting tool type, fixture torsion type and vacuum adsorption type.

In terms of the design of cutter shear end-effector, Li et al. designed a flipping-shear end-effector based on the biological characteristics of spherical fruits and cut the stem of spherical fruits through the bite of the tool and the flip of the clamping mechanism. The designed end-effector is shown in Figure 2. (a) [6]. In the orchard experiment, the success rate of picking citrus fruit, apple fruit and kiwi fruit is more than 80%. In terms of the design of the fixture torsion end effector, Yu et al. adopted a flexible three-claw claw loaded with pressure film to pick tomatoes by rotating and twisting, thus reducing the damage to the tomato skin. The designed end effector is shown in Figure 2. (b) [7]. In terms of the design of vacuum adsorption end-effector, Abundant Robotics of the United States designed an end-effector that used vacuum tubes to adsorb apples. Its simple form enhanced the reliability of the equipment. The designed end-effector is shown in Figure 2 (c) [8].

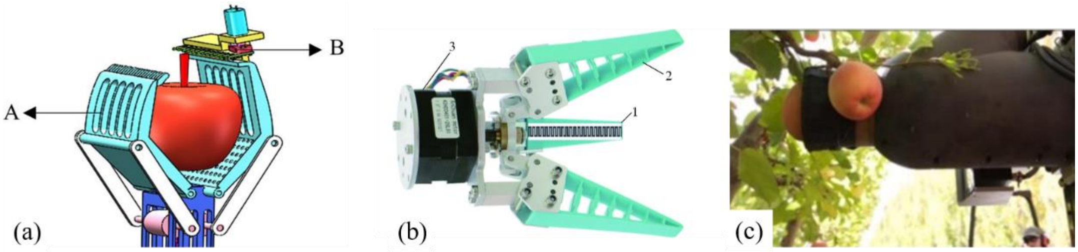

Fig. 2 Three end effectors. (a) cutter shear [6], (b) fixture torsion [7], (c) vacuum adsorption [8].

3. Perception and Decision System

3.1. Visual System

For fruit target positioning, scholars have proposed many research methods, among which the more extensive based on monocular camera, stereo vision matching, depth camera, laser rangefinder three-dimensional positioning. The 3D positioning method based on monocular camera adopts passive ranging, which is simple to use, but the identification and positioning accuracy is low and easy to be affected by external factors such as illumination. The 3D positioning method based on stereo vision matching generally uses binocular camera method to increase the perception range of the vision system and increase the accuracy, but the disadvantage is that the use process is complicated, the calculation time is long, and the computing power is high. The majority of 3D positioning methods that rely on depth cameras use RGB-D cameras, which enable more direct acquisition of depth information. However, these methods are susceptible to interference caused by reflections. The three-dimensional positioning method based on laser rangefinder mainly uses infrared laser, which has high speed and high precision, but it is easy to lose focus when the measuring distance is too long and false signals are easy to be generated when the branches and leaves are blocked.

3.2. Vision-Based Analysis System

The vision system is equivalent to the "eyes" of the robot and then assists the robot to achieve accurate positioning and grasping of the fruit. The visual analysis system applied to fruit picking robot mainly consists of two technologies: object recognition and three-dimensional positioning.

To recognize fruits, two-dimensional information of fruits should be obtained first. Generally, the fruit can be recognized by extracting features from a single frame image. However, in fruit picking, due to natural environmental factors such as uneven lighting, occlusion of branches and leaves, and overlapping of fruits, the machine will be more difficult for visual recognition. Therefore, it is not only necessary to perform image processing according to the physical properties of fruits, but also to introduce deep learning algorithms to increase the recognition accuracy. The following introduces several research on fruit recognition using machine vision in recent years. Wang et al. proposed an image processing algorithm for citrus. Through image enhancement, denoising and segmentation pre-processing operations on photos taken by citrus picking robots, edge operators were selected to realize the recognition of citrus [9]. The recognition success rate of the method was 97% for single citrus without branches and leaves, 90% for single citrus with branches and leaves, and 80.6% for multiple citrus fruits overlapping. Zhang et al. proposed a target identification and positioning scheme based on the improved YOLOv5s, GNPD-YOLOv5s, which is small in size, fast in calculation and strong in portability, and can provide the manipulator with pose adjustment to avoid branches and leaves, and the maximum depth positioning error of pepper is 1.84mm. Meet the demand of pepper picking robot for pepper recognition [10].

After the fruit is identified, it is necessary to obtain accurate three-dimensional positioning in order to make the end effector reach the exact position and realize the fruit picking. After obtaining the two-dimensional information of the fruit, it is usually necessary to obtain the depth information through binocular vision or RGB camera. Zhou et al. adopted binocular vision and eye-eye calibration based on Eye-in-Hand to realize three-dimensional positioning and picking of camellia fruit [11]. In the experiment, the median error between the real coordinate and the measured coordinateof camellia fruit is 23.524 mm, which can realize the demand of picking. Fu et al. proposed a visual recognition system based on RGB-D depth camera, which is suitable for apple orchards with an average accuracy of 89% [12]. Zhang et al., also proposed a method for tomato skew picking point identification and positioning based on RGB-D information fusion. The test showed that under complex background color, the success rate of picking points recognition is 93.83%, which met the real-time requirements of automatic picking [13].

4. Discussion

Through the investigation and summary of the literature in recent years, it is found that there are some problems in fruit picking robots. First of all, since fruit tree picking robots need to carry out image recognition processing, robot arm positioning and movement, control system calculation and other steps, most fruit tree picking robots are not efficient. Secondly, although the current recognition rate of fruits is as high as 90%, the data are generally derived from greenhouse orchard experiments, and there are often many influencing factors in real orchards, and the recognition rate is low. Finally, according to the literature reviewed, a fruit tree picking robot only picks fruit of one kind of fruit tree, and the picking robots of various varieties lack commonality.

In view of the existing problems, this paper summarizes several future development directions to realize the automation, intelligence and commercialization of fruit tree picking robots. Firstly, through the integration of control systems for each component to achieve automation and the incorporation of Internet of Things technology, operational data is processed on a cloud platform to enhance processing speed and control while enabling intelligent picking. Then, the picking speed of single robotic arm is slow, and the collaboration of multiple robotic arms can significantly improve the picking efficiency. Secondly, the real orchard situation is complex, it is not only necessary to improve the hardware and software of the fruit tree picking robot, but also needs to standardize planting, reduce the shade of branches and leaves by pruning, and improve the picking efficiency. Finally, for fruits with similar physical parameters, a visual recognition system is integrated to carry out a general design of the expansion equipment, that is, by replacing the end effector, different varieties of fruit can be picked.

5. Conclusion

Based on the recent literature review, this paper analyzes the research status and key technologies of fruit tree picking robots, including the execution system and the perception and decision system. First of all, the research significance and background of fruit tree picking robot are fully discussed. Secondly, the author makes a comprehensive analysis of the execution system from two aspects: mobile platform and picking mechanism. Then, the perception and decision system applied to the fruit tree picking robot is analyzed from two aspects: the vision system and the analysis control system. Finally, this paper analyzes the problems of fruit picking robot in picking efficiency, picking speed, influencing factors and generality, and looks forward to the future. In the future, fruit tree picking robots will develop rapidly in the direction of automation, intelligence and commercialization.

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