Overview of Apple Picking Robots

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Abstract. In recent years, with the decreasing rural population and increasing fruit tree yield, the picking industry has seen a growing need for the emergence of picking robots. This paper first introduces the different types of apple-picking robots and then analyzes the advantages and disadvantages of their various transmission methods to identify the most suitable method for transmitting power for apple picking. Finally, the design of end-effector types for apple picking is summarized. In order to achieve high efficiency and results in apple picking, research has been done mainly on the mechanized picking of apples as a fruit. The presence of such picking robots also saves a lot of time and labor costs.

Keywords: Picking robot, Robotic arm, Actuator

1 Introduction

In recent years, as rural populations continually migrate to urban areas, the labor force in rural areas has significantly diminished. In the cultivation of fruits and vegetables in rural areas, the picking process has become a major issue [1]. Harvesting fruit requires a large labor force within a short period of time, is time-consuming, and accounts for nearly half of the workload in the entire fruit tree cultivation process. Furthermore, with the diversification of fruit and vegetable planting, there are now fruits that hang at high altitudes, making the picking process even more dangerous and inefficient. Even the most common apple picking requires a substantial amount of human labor. To change the current situation, the need for fruit picking robots is becoming increasingly urgent. Therefore, fruit picking robots are becoming more important in people's lives. Specifically, the emergence and development of apple picking robots have significantly improved the process of apple harvesting, saving a lot of time and labor costs.

Countries around the world place significant emphasis on fruit-picking robots. For instance, in 2008, a Belgian research team developed a six-degree-of-freedom jointed apple-picking robot and created a flexible end-manipulator, which effectively reduces damage to apples upon contact. Experimental results showed that the robot could pick 8-10 apples per minute, with a success rate as high as 80%[2]. Research on fruit-picking robots started relatively late in China compared to other advanced and developed countries, but in recent years, an increasing number of Chinese universities

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have begun to focus on the development and application of picking robots, making substantial progress. For example, in 2010, a Chinese research team developed a five-degree-of-freedom jointed apple-picking robot, another high-degree-of-freedom apple-picking robot. Additionally, China independently developed a crawler-based apple-picking robot, which has brought benefits to apple harvesting[2].

This article focuses on apple-picking robots, covering the different types of picking robots, methods of fruit transportation and mechanical motion transmission, and various types and applications of end-effector, etc., with the aim of better understanding of the existing apple-picking robots.

2 Types of Apple-Picking Robots

The picking robotic arm is the core component of the apple-picking robot. With the diversity of fruit cultivation, picking robots have higher demands on the picking robotic arm. The design quality of the picking arm greatly affects picking accuracy, proficiency, and success rate. Additionally, the robotic arm is closely connected with the vision module, intelligent sorting system, and end effector at the front and rear[3]. Therefore, a well-designed and correctly chosen robotic arm will significantly enhance the efficiency of fruit picking.

The existing types of apple-picking robots are mainly divided into cylindrical coordinate type, Cartesian coordinate type, straight coordinate type and multi-joint type. Different types are able to meet various apple-picking requirements.

2.1 Cylindrical Coordinate type

The working range of this robot is of a fan-shaped type. As shown in Figure 1, it is composed of a movable rod and a rotating rod. The working method is centered on itself, using the end effector to pick fruits within a fan-shaped area around it. This type of robot is characterized by its small footprint, convenience, flexibility, and high precision within the designated area, making it suitable for picking fruits that require harvesting within a stationary range. However, the overall picking range of the robot is limited to within a cylindrical area and it is not easy to move.

2.2 Cartesian Coordinate Type

The working range of this robot involves linear motion in either horizontal or vertical directions for picking fruits. As shown in Figure 2, it consists of three mutually perpendicular axes that define the working range of the end effector. The end effector can slide linearly along these axes to perform its tasks. This type of robot features a wide picking range, high end-effector picking precision, simple operation, and extensive picking coverage, making it suitable for harvesting fruits planted over large areas or according to specific patterns. However, the robot occupies a relatively large area and moves along linear tracks, resulting in lower efficiency for complex picking tasks.

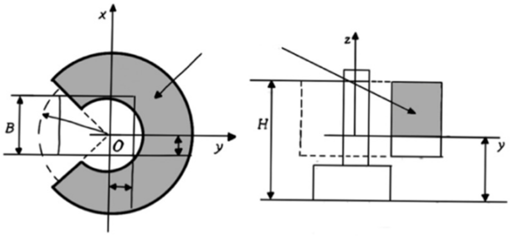

Fig. 1. Cylindrical coordinate type.

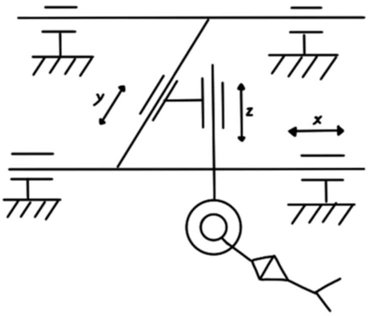

Fig. 2. Cartesian coordinate type.

2.3 Polar Coordinates

This type of robot operates within a spherical working range. As shown in Figure 3, it consists of a mechanical arm made up of multiple rotational axes that form coordinated shapes. It moves systematically according to coordinates, and the end effector performs picking tasks at the end of the arm. Such robots are characterized by flexibility, high mobility, the ability of the robotic arm to move freely within a certain height, and sturdy construction. They are suitable for picking fruit in complex areas or those growing at higher locations. However, the overall robot is relatively heavy, the end effector is difficult to control, and the picking accuracy is low.

2.4 Multi-Joint Type

This robot operates within a spherical curved surface range, offering a wider picking range compared to polar coordinate and Cartesian coordinate robots. As shown in Figure 4, it is composed of multiple rotating shafts forming multiple joints, driving several segments of the mechanical arm. This allows for more flexible operation and picking. This type of robot boasts high flexibility and a relatively large picking range. However, due to its complex structure, it is difficult to control and achieve precise picking. The end effector cannot pick overly heavy fruits. It is suitable for picking fruits that grow inside the tree or lighter fruits.

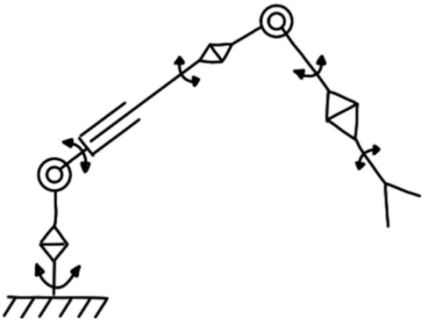

Fig. 3. Polar coordinate type.

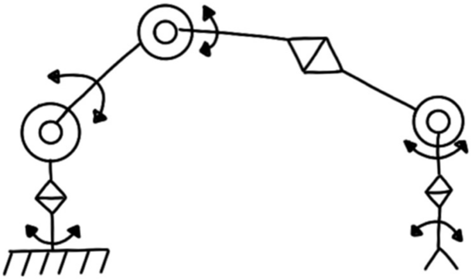

Fig. 4. Multi-joint type.

The selection of the picking robotic arm needs to be adjusted according to its practical use and the method of apple cultivation. Different methods of apple cultivation have the most suitable picking techniques. Modern apple cultivation is moving towards a simplified and refined approach known as "dwarf and dense planting." The aim is to better accommodate the operation of the picking mechanical arm, thereby reducing bending and complex operations when the mechanical arm is picking apples.

3 The Transmission Method of the Picking Robotic Arm

For apple-picking robots, the transmission of the picking robotic arm must meet the requirements for apple picking. Currently, there are four main transmission methods for apple picking, with the first two being more commonly used and better suited to the demands of apple picking.

3.1 Screw-nut Pair Transmission

The screw nut pair is mainly divided into sliding screw and rolling screw. As shown in Figure 5. The lead screw is primarily used for machinery processing and linear transmission, allowing the robotic arm to extend and retract freely for picking, while requiring less starting force. The sliding screw is a standard screw with lower precision and less flexibility compared to the rolling screw.It is generally used in picking fruit with low precision and uncomplicated operation. The rolling screw, composed of multiple ball bearings, moves in a rolling motion, providing an additional layer of lubrication compared to the sliding screw. This results in significantly higher accuracy, lower friction, greater durability, and an efficiency of 3-4 times higher than that of the sliding screw. However, its major drawback is shorter endurance, as the ball bearings cannot operate continuously for extended periods. Both types of screws are suitable for apple picking, with the rolling screw facilitating faster and safer transportation of apples into the production line[4].

3.2 Gear Rack Pair Transmission

The primary principle of the gear and rack pair is to rotate the driving gear, which in turn drives the driven gear to move linearly along the rack, as shown in Figure 6. The primary advantage of gear transmission is its stability and precise meshing; different gears can drive gears in any direction, accurately reaching the target position and angle. The disadvantages are the high difficulty and cost of manufacturing, and it may occupy significant space. The starting force required is also substantial, making it unsuitable for prolonged operations. It is suitable for slow, heavy-duty picking tasks. This transmission method is used for apple transportation in large-scale apple cultivation, enabling the robotic arm to pick apples more efficiently. It is currently used in Cartesian coordinate robots.

Fig. 5. Screw-nut pair.

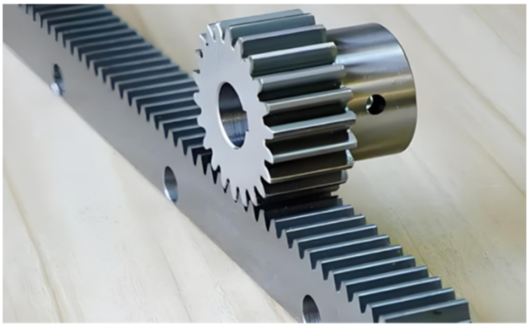

Fig. 6. Gear rack pair.

3.3 Synchronous Toothed Belt Drive

The working principle of a synchronous toothed belt is that a toothed belt reverses its direction along gears of corresponding sizes at the corner. As shown in Figure 7, the protrusions on the gear mesh well with the grooves on the belt, achieving low wear, high precision, and high efficiency, as well as enabling rapid transmission. The disadvantage is that it requires very high installation accuracy, and it is difficult to maintain precise control during actual operation, therefore it is difficult to find an advantageous application in the fruit-picking industry. However, it is still suitable for long-distance high-speed transport transmission [6].

3.4 Linear Motor Drive

The principle of the linear motor is to directly convert electrical energy into mechanical energy to ensure linear motion, which is the simplest and most straightforward mode of transmission, as shown in Figure 8. Consequently, it brings advantages such as a simple structure, easy operation, quick response, and virtually zero wear, making it suitable for short-distance, high-force transmission scenarios. However, since agricultural fruit picking generally does not require such short-distance, high-intensity transmission, combined with power supply issues, the application of linear motor drive in this field is quite challenging.

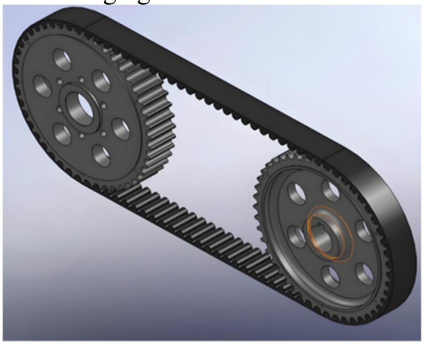

Fig. 7. Synchronous Toothed Belt.

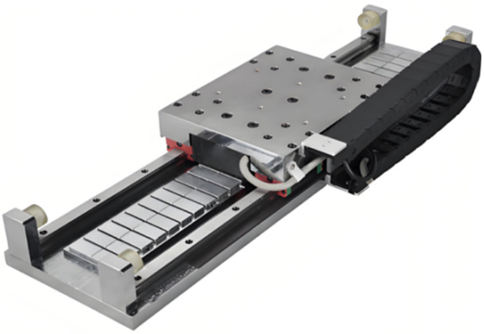

Fig. 8. Linear Motor.

The latter two transmission methods are only suitable for use in some special circumstances to harvest apples under specific growing conditions.

4 End Effector

To find the most suitable end effector for apple picking, it is first necessary to analyze the characteristics and picking requirements of the target apples. Apple trees are deciduous and their fruits are relatively regular spherical shapes. The fruit is hung on the branch through the connection of fruit stem and fruit tree branch. There are generally two methods for manual harvesting. One method is to cut the stem directly and catch the apple, and the other method is to stabilize the apple, then use the index finger to press the stem upward to break it off from the base of the branch and remove the fruit. The second method is not only aesthetically pleasing and tidy but also effectively avoids the infection that can result from cutting the stem [7].

4.1 End Effector Design Objectives

The design of the end effector is inspired by the method of manual picking. The majority of end effectors utilize a technique similar to the second method of manual apple picking, allowing them to successfully replace human hand-picking while minimizing damage to the fruit trees and apples. The end effector should accurately handle fruits of moderate size, separate the fruit stems from the branches by breaking them off at the base, and be compact and lightweight. Moreover, it should offer the advantages of high efficiency and low cost. The following diagram shows a schematic of the end effector(figure 9 and figure 10).

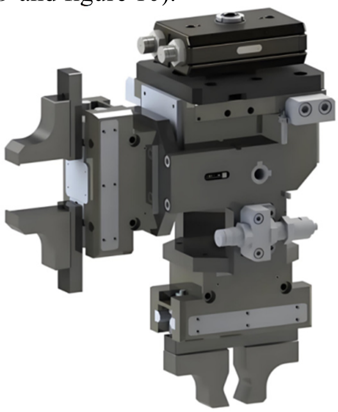

Fig. 9. End effector 1[5]

Fig. 10. End effector 2 [5]

4.2 End Effector Material Selection

Since the end effector is located at the end of the robotic arm, the materials used must be sufficiently light. However, because different parts of the end effector perform different functions, a single material cannot be used throughout. The part near the robotic arm, which supports the end effector frame, can be made from lighter aluminum. The part near the fruit, responsible for grasping the fruit and flexible operation, can use sturdier iron due to its high strength and durability for continuous motion. Similarly, the connecting shafts responsible for the rotation of various axes can also utilize high-durability iron. The parts that come into contact with the fruit need to be made of soft and flexible materials, capable of securely gripping the fruit without causing any damage. Suitable materials include lightweight yet high-strength nylon. Additionally, the fingers of the end-effector should be coated with silicone material to minimize any harm to the fruit. The overall end-effector is constructed using different materials for each part, ensuring that they work together for efficient picking while also reducing the overall weight. This approach significantly decreases both the precision requirement and the operational difficulty [8].

4.3 Main Types of End-Effectors

Within end-effectors, there is a crucial component for grabbing apples known as the "chuck." The chuck is responsible for grasping the apples and is shaped like an arc-shaped claw.

Mechanical Rotary Type： The working method of this end effector is to use a chuck to grasp the apple and then twist the apple off the branch by rotating the chuck. This method of picking is simple and quick, but it has a significant drawback[9]. During the rotation process, the chuck may fail to twist off the apple if the connection between the apple and the branch is too strong, or the twisting force may be too great, damaging the integrity of the apple or branch. Consequently, this type of end effector has certain limitations in apple picking.

Mechanical Down-Pulling Type:The working method of this end effector is to use a chuck to grasp the apple and then pull it downward directly, causing the apple to detach at the stem-branch connection point, thus achieving the purpose of picking. This method is easy to position, efficient, and quick, but it also has the risks of breaking branches and damaging the apple itself, which brings inconvenience to subsequent transportation and other processes. As a result, its application is also relatively limited.

Mechanical Air Suction Type: This type of end-effector operates by using a chuck to grip the apple while generating suction to hold the apple and then pick it off. This method is relatively efficient and easier to operate, as the suction automatically corrects minor deviations and causes less damage to the apple. The primary challenge is controlling the suction force and its source of power. End-effectors that can achieve this are widely used in apple picking.

Mechanical Tool Acquisition Type: This type of end-effector operates by using a chuck to grip the apple, then coordinating with scissors on the end-effector to minimize damage to the tree branches during picking. Another form involves using a chuck to grip the fruit stem, with a small knife extending inside the chuck to cut the stem and pick the apple. These two types represent another commonly used category of end-effectors.

5 Conclusion

This article explains the significance of picking robots for apples; it describes the types, working principles, advantages, and disadvantages of each part of the apple-picking robot. It highlights the importance of picking robots for apples and other fruits and vegetables, demonstrating how the advent of these robots has made fruit picking more efficient and convenient.

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