

# Kinematic Design and Optimization of the Mechanical Arm for Agricultural Product Picking Robots

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## Abstract

This article discusses the kinematic design and optimization of the mechanical arm of agricultural product picking robots. Firstly, the background and significance of the development of agricultural product picking robots were expounded, emphasizing the key role of kinematic design of mechanical arms in picking operations. Then, the key points of kinematic design are introduced from aspects such as the structural design of the robotic arm, the configuration of degrees of freedom, and the determination of the range of motion, and the influence of different design factors on the picking performance is analyzed. Then, the kinematic optimization strategies of the robotic arm are discussed, including structural optimization, motion coordination optimization and adaptive optimization. Finally, the future development of kinematic design and optimization of the mechanical arm of agricultural product picking robots is prospected, aiming to provide theoretical references for improving the performance and picking efficiency of agricultural product picking robots.

**Keywords:** Agricultural product picking robot; Mechanical arm; Kinematic design; Kinematic optimization.

## 1. Introduction

With the continuous growth of the global population and the improvement of people's living standards, the demand for agricultural products keeps increasing. The traditional manual picking method has exposed many problems when dealing with large-scale agricultural production. On the one hand, labor costs are constantly rising, especially in developed countries. The shortage of agricultural labor has led to high costs for manual picking <sup>[1]</sup>. On the other hand, manual picking is inefficient and labor-intensive, making it difficult to meet the timeliness requirements for agricultural product picking. Many agricultural products have specific maturity periods. If they are not picked in time, their quality will decline, causing serious economic losses. <sup>[2]</sup>

As an intelligent device capable of replacing manual labor for picking operations, agricultural product picking robots have significant advantages such as high efficiency, accuracy, and continuous operation. It can accurately identify target agricultural products in complex and changeable farmland environments and control the mechanical arm to complete the picking actions, effectively solving the predicament faced by manual picking <sup>[3]</sup>. The robotic arm is one of the core components of the agricultural product picking robot, and its kinematic performance directly affects the efficiency and quality of the picking operation. A reasonable kinematic design of the robotic arm enables it to move flexibly within the working space, accurately reach the target picking position, and complete the picking action. Therefore, conducting related research has significant practical significance.

## 2. Characteristics of Agricultural Product Picking Operations and Design Indicators of Robotic Arms

### 2.1 Characteristics of Agricultural Product Picking Operations

#### 2.1.1 Diversity of Target Objects

There are significant differences among various types of agricultural products in terms of shape, size, color and texture. For instance, apples are round in shape, with a diameter generally ranging from 6 to 10 centimeters and have a relatively hard texture. Strawberries are heart-shaped, with a diameter of about 2 to 3 centimeters. They are relatively soft and prone to damage <sup>[4]</sup>. This diversity poses different requirements for the grasping and picking methods of robotic arms. For agricultural products with regular shapes and high hardness, the clamping picking method can be adopted. Agricultural products with smooth surfaces and relatively soft textures, adsorption or gentler grasping methods should be adopted to avoid causing damage to the agricultural products.

### 2.1.2 Complexity of the Working Environment

The farmland environment is complex and changeable, with many uncertain factors. One of the common problems is the obstruction of branches and leaves. In fruit tree cultivation, dense branches and leaves may block the target agricultural products, making it difficult for mechanical arms to accurately identify and locate them. In addition, the undulating terrain can also bring difficulties to the picking operation. The slopes and height differences of different plots vary, and the mechanical arm needs to have a certain adaptability to ensure stable operation under different terrain conditions. Meanwhile, there may also be obstacles such as weeds and stones in the farmland. The robotic arm needs to have the ability to avoid obstacles to prevent collisions with these obstacles.

### 2.1.3 High Timeliness Requirements

Agricultural products have a specific maturity period, and the picking time window is relatively short. Take grapes as an example. Their ripening period is generally in summer. If they are not picked shortly after ripening, they will be overripe and rot, affecting their quality and sales <sup>[6]</sup>. Therefore, the robotic arm needs to have a high picking efficiency to complete large-scale picking tasks within a limited time. This requires the mechanical arm to have fast movement speed and precise movements, capable of quickly and accurately reaching the target picking position and completing the picking actions.

### 2.1.4 High Precision is Required

During the picking process, it is necessary to accurately identify the position and posture of the target agricultural products and control the mechanical arm to precisely reach the picking point. For some agricultural products with high requirements for picking accuracy, such as blueberries, whose fruits are small and grow densely, the mechanical arm needs to have high-precision positioning and grasping capabilities to avoid mistakenly picking unripe fruits or causing damage to the plants <sup>[7]</sup>. Precise picking not only ensures the quality of agricultural products but also reduces damage to plants, which is beneficial to the subsequent growth of crops.

## 2.2 Design Specifications of the Robotic Arm

According to the characteristics of agricultural product picking operations, the design indicators of the robotic arm mainly include: the working space should be able to cover the agricultural product picking area to reach all target positions; The configuration of degrees of freedom should be reasonable to ensure that the robotic arm has sufficient flexibility to adapt to the picking requirements of agricultural products of different shapes and postures. It should have a certain load capacity, be able to carry picking tools and agricultural products and ensure stable movement. The movement speed should be relatively high to enhance the picking efficiency, but both stability and accuracy should be taken into account. The precision of motion must meet the requirements for agricultural product picking, which directly affects the accuracy of picking. It should also be able to adapt to different farmland environments and types of agricultural products and possess certain universality and scalability.

## 3. Kinematic Design of Robotic Arms

### 3.1 Mechanical Arm Structure Design

The structural design of a robotic arm is the foundation of kinematic design. Common robotic arm structures include series structures and parallel structures. The series-structured robotic arm has the advantages of simple structure, large working space and good flexibility, and is suitable for operation scenarios such as agricultural product picking that require large-scale movement. Parallel structure robotic arms have the characteristics of high rigidity, strong load-bearing capacity and high motion accuracy, but their working space is relatively small.

Series-structured robotic arms are typically composed of multiple connecting rods and joints. The types of joints mainly include rotary joints and mobile joints. Rotating joints can achieve relative rotation between connecting rods, while moving joints can achieve relative movement between connecting rods. In agricultural products picking robotic arms, rotary joints are usually adopted to achieve flexible movement of the robotic arm.

### 3.2 Degrees of Freedom Configuration

Degrees of freedom refer to the number of degrees of freedom that a robotic arm can move independently. A reasonable configuration of degrees of freedom is crucial to the motion performance of the robotic arm. Generally speaking, the

more degrees of freedom a robotic arm has, the higher its flexibility will be, but at the same time, it will also increase the complexity and cost of control.

For agricultural products picking robotic arms, it is usually necessary to configure six degrees of freedom, including three position degrees of freedom and three attitude degrees of freedom. Three positional degrees of freedom enable the robotic arm to reach any position in three-dimensional space, while three attitude degrees of freedom can adjust the attitude of the end effector of the robotic arm to meet the picking requirements of agricultural products of different shapes and attitudes. For instance, when picking apples, the robotic arm needs to adjust the Angle of the end effector so that it can accurately fit the apples and carry out the picking.

### **3.3 Determination of the Range of Motion**

The range of motion refers to the maximum Angle at which each joint of the robotic arm can rotate or the maximum distance it can move. The determination of the range of motion requires comprehensive consideration of factors such as the size of the agricultural product picking area, the distribution of agricultural products, and the structural dimensions of the robotic arm.

When determining the movement range of the robotic arm, it is necessary to ensure that the robotic arm can cover the entire picking area and avoid collisions with the surrounding environment. At the same time, the movement limit of the robotic arm also needs to be considered to avoid damaging the robotic arm due to excessive joint movement. For instance, when designing a mechanical arm for picking strawberries, due to the relatively low height of the strawberry plants, the vertical movement range of the mechanical arm can be relatively small. When picking citrus fruits, the citrus trees are relatively tall, and the mechanical arm needs to have a large vertical movement range.

### **3.4 End Effector Design**

The end effector is the part of the robotic arm that comes into direct contact with agricultural products, and its design directly affects the picking effect. The design of end effectors should be customized according to the characteristics of different agricultural products. Common types of end effectors include clamping type, adsorption type and cutting type, etc.

The clamp-type end effector is suitable for agricultural products with regular shapes and high hardness, such as apples and citrus fruits. It achieves picking by clamping the surface of agricultural products. When designing, the magnitude and uniformity of the clamping force need to be considered to avoid damaging agricultural products. Adsorption end effectors are suitable for agricultural products with smooth surfaces and relatively soft textures, such as strawberries and tomatoes. It utilizes the principle of negative pressure adsorption to adsorb agricultural products onto the end effector. When designing, it is necessary to ensure stability and sealing of the adsorption. The cutting end effector is mainly used for picking agricultural products that need to have their stem cut off, such as grapes and watermelons. It separates agricultural products from plants through the cutting action of the knife. When designing, the sharpness of the knife and the magnitude of the cutting force need to be taken into consideration.

## **4. Kinematic Optimization Strategies for Robotic Arms**

### **4.1 Structural Optimization**

Structural optimization is one of the important means to improve the motion performance of robotic arms. By optimizing the structural parameters such as the connecting rod length and joint position of the robotic arm, the performance indicators of the robotic arm, including its working space, flexibility and load capacity, can be improved.

During the process of structural optimization, bionic design methods can be adopted, drawing on the structure and movement principles of biological joints to design a more reasonable and efficient mechanical arm structure. For instance, by imitating the structure and movement pattern of human arms, mechanical arms with flexibility similar to that of human arms can be designed. In addition, a lightweight design concept can be adopted. By selecting lightweight materials and optimizing the structural layout, the weight of the robotic arm can be reduced, energy consumption can be lowered, and the movement speed and accuracy can be enhanced.

### **4.2 Optimization of Motor Coordination**

During the movement of a robotic arm, the joints need to coordinate and cooperate with each other to achieve smooth and accurate movement. The optimization of motion coordination aims to enhance the motion synchronization and coordination among the joints of the robotic arm and reduce vibration and shock during the movement process.

The optimization of motion coordination can be achieved by optimizing the motion control algorithm of the robotic arm. For instance, by adopting an algorithm based on Model Predictive Control (MPC), the movement trajectories of each joint of the robotic arm are planned in advance according to the dynamic model and the moving target, and real-time adjustments and optimizations are made to ensure that the robotic arm moves along the predetermined trajectory. In addition, sensor feedback technology can also be adopted to monitor the movement status of the robotic arm in real time, such as joint angles, speed and acceleration, etc. Based on feedback information, the control strategy can be adjusted in a timely manner to improve the movement coordination.

### **4.3 Adaptive Optimization**

The environment for agricultural product picking operations is complex and changeable. The robotic arm needs to have good adaptability to cope with different farmland environments and types of agricultural products. Adaptive optimization mainly includes the optimization of the motion parameters and environmental perception capabilities of the robotic arm.

In terms of motion parameter optimization, parameters such as movement speed, acceleration and joint Angle of the robotic arm can be adjusted according to different picking tasks and environmental conditions to enhance picking efficiency and accuracy. For instance, when picking densely growing agricultural products, the movement speed of the mechanical arm can be appropriately reduced to avoid colliding with the surrounding plants.

In terms of optimizing environmental perception capabilities, the robotic arm can be equipped with various sensors, such as visual sensors, force sensors, and distance sensors, to perceive real-time information about the surrounding environment, such as the location and posture of agricultural products, and the distribution of plants. Based on the information fed back by the sensors, the robotic arm can automatically adjust its movement strategy to achieve adaptive picking. For instance, when the visual sensor detects an obstacle ahead, the robotic arm can automatically avoid it and continue to complete the picking task.

## **5. Development Prospects of Kinematic Design and Optimization of Mechanical Arms for Agricultural Product Picking Robots**

### **5.1 The Development of Multi-sensor Fusion Technology**

In the future, the mechanical arms of agricultural product picking robots will pay more attention to the application of multi-sensor fusion technology. By fusing the information from various sensors such as visual sensors, force sensors, and distance sensors, it is possible to perceive the surrounding environment and target agricultural products more comprehensively and accurately, thereby enhancing the decision-making ability and picking accuracy of the robotic arm. For instance, by integrating information from visual sensors and force sensors, robotic arms can more accurately assess the maturity and grasping force of agricultural products, achieving more intelligent picking.

### **5.2 Application of Artificial Intelligence Technology**

Artificial intelligence technology will play an increasingly important role in the kinematic design and optimization of the mechanical arms of agricultural product picking robots. By using deep learning algorithms, robotic arms can automatically learn and recognize different types of agricultural products and their characteristics, improving the accuracy and efficiency of target recognition. Meanwhile, artificial intelligence technology can also be used to optimize the motion control strategy of robotic arms, achieving more autonomous and efficient picking operations. For instance, through reinforcement learning algorithms, robotic arms can continuously learn the optimal motion trajectories and control parameters in practice, thereby enhancing their picking performance.

### **5.3 Integration with Agricultural Internet of Things**

The mechanical arm of the agricultural product picking robot will be deeply integrated with the agricultural Internet of Things. Through the agricultural Internet of Things, robotic arms can interact with other agricultural equipment and systems for information exchange and collaborative work, achieving intelligent management of agricultural production. For instance, robotic arms can automatically adjust picking plans and strategies based on the growth information of

agricultural products and market demand information provided by the agricultural Internet of Things, thereby enhancing the efficiency and competitiveness of agricultural production.

#### 5.4 Modular and Standardized Design

In order to reduce the design and manufacturing costs of mechanical arms and enhance their versatility and scalability, the mechanical arms of agricultural product picking robots in the future will develop in the direction of modularization and standardization. By dividing the robotic arm into multiple functional modules, such as joint modules, connecting rod modules and end effector modules, etc., it can be flexibly combined and replaced according to different picking requirements. At the same time, formulating unified standards and norms is conducive to the mass production and wide application of robotic arms.

### 6. Conclusion

The kinematic design and optimization of the mechanical arm of agricultural product picking robots are the keys to improving the efficiency and quality of picking operations. This paper analyzes the characteristics of agricultural product picking operations and the design indicators of robotic arms, and introduces the key points of kinematic design of robotic arms, including structural design, degree of freedom configuration, determination of motion range and end effector design, etc. Meanwhile, the optimization strategies for the kinematics of the robotic arm were discussed, including structural optimization, motion coordination optimization and adaptive optimization. In the future, with the development of multi-sensor fusion technology, artificial intelligence technology, agricultural Internet of Things, and the advancement of modular and standardized design, the performance of agricultural product picking robot arms will continue to improve, providing strong support for the modernization of agriculture.

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