Advances in Engineering Research, volume 154
International Conference on Mechanical, Electrical, Electronic Engineering & Science (MEEES 2018)

Design and Prototype Verification of a Fruit Harvesting Picker

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Keywords: Fruit harvesting, fruit collecting, telescopic picker.

Abstract. The paper proposes a design scheme for a fruit harvesting picker that can realize precise and efficient continuous operations of fruit picking through ingenious mechanisms, so as to address the problems currently existing in fruit picking operations, such as low efficiency and no security assurance of high-attitude operators and reduce the picking costs. With the functions to pick, collect and pack fruits, the picker is comprised of three major mechanisms: Transmission Mechanism, Picking Mechanism and Fruit Collecting Mechanism. The picker, whose shape and size can be changed flexibly, is not only used for picking a single type of fruit, but also designed to be able to pick various kinds of fruits, which can be realized through minor changes of its cutter. Based on the design scheme, a prototype was built, and picking experiments were carried out, which proved the effectiveness of the design.

1. Introduction

Variety of methods can be used to pick fruits, including manual picking, semi-mechanized picking, mechanized picking, and intelligent robotic picking and so on. [1] Manual picking is carried out mainly in three ways: (1) picking directly by hands; (2) picking with a half-open clamp; (3) picking with a stick equipped with a sickle head. These ways all have some deficiencies. When the fruit tree is high with fragile branches, the first way is not only unsafe but also easy to damage the tree. The second way is only suitable for picking the fruits that have a long stalk, while it can also easily make the stalk fall off and thus drop the fruit. The drawback of the third way is that the pedicle of the fruit can be easily broken, resulting in the falling of the fruit on the ground and breaking the stubble of the branch whose growth will be affected. As for semi-mechanized picking, it generally makes use of tools like automatic lift trolley or moving trailer to adjust the relative position of people and fruits, but the fruits are ultimately picked by hands. Mechanized picking is highly efficient but may seriously damage the fruits. Robotic picking greatly reduces the demands for labor and guarantees personal safety, while the current intelligent robots cannot fully meet the requirements of fruit harvesting and have high costs. [2]

This paper puts forward a device for workers on the ground to pick the fruits on the tree. It first proposes the system level design of the fruit picker through concept development of the product, then divides the picker into three sub-assemblies, and finally designs or selects every mechanical part to finish the design of the picker. On the completion of the design, the first-generation prototype was built based on the design scheme, and corresponding experiment on fruit picking was conducted.

2. Concept Development

2.1 Design Scheme.

In this device, the rotation of the motor drives the rotation of the synchronous wheel, and the movement is transmitted to the shaft through the synchronous pulley so as to drive the rotation of the pinion. The rack could move up and down with the pinion's rotation and finally drive the cutter to move up and down, thus realizing fruit picking operations.

The scheme has following advantages:

(1) The power is provided by motor, which saves labor;

(2) Electrical energy has no pollution to the orchard, making this method more environmentally friendly;

(3) The combination of picking and collecting enhances the efficiency of fruit harvesting;

(4) Workers do not need to climb the tree, and their safety can be thus guaranteed;

(5) There is no direct damage to the trees during the picking.

2.2 System Level Design.

The fruit picker consists of a frame and three mechanisms: Transmission Mechanism, Picking Mechanism and Collecting Mechanism. The structure and function of each mechanism is shown in the table.

Table 1. Sub-assembly Mechanism Concept

Name	Components	Function
Transmission Mechanism	Rack, Pinion, Synchronous Pulley, Shaft, Bearings, Motors.	Power Transmission
Picking Mechanism	Cutter	Picking Fruits
Collecting Mechanism	String Bag, Collection Box	Collecting Fruits

The device combines fruit picking and collecting together, with its lever arm being able to automatically stretch out and draw back. In this way, the worker only needs to operate the device on the ground and the fruits can be picked. After being picked, the fruits will fall safely and smoothly into the collection box under the action of gravity and the guidance of net rope, which largely reduces the workload and risks the worker faces and creates no pollutants.

3. Mechanism Design

3.1 Rack and Pinion Mechanism.

The stress and strain of the rack vary by position. When the rack is horizontal, it is in an extreme position and the bending moment reaches the maximum value, which means that the fracture is most possible to occur. At this time, the rack can be simplified as a cantilever beam model for analysis and calculation, in which F is the maximum possible weight for the cutter, G is the weight of the rack, and L is the length of the rack. W_z Is the section modulus in bending, b is the width of the cross section and h is the height of the cross section.

The rack selected for the research has a size of $20\text{mm} \times 20\text{mm} \times 1500\text{mm}$. In order to reduce the weight of the mechanism, its material is selected as Nylon 6 with 15% glass fiber whose density is $1.25\,\text{g}/\text{cm}^3$ and tensile strength is 103MPa. The safety factor is 2. The calculation is as follows. [3]

The maximum bending moment in the rack is:

$$M = F \times L + G \times \frac{L}{2} = 41.5N \cdot m \tag{1}$$

The section modulus in bending is:

$$W_z = \frac{bh^2}{6} = 1.3 \times 10^{-6} m^3 \tag{2}$$

$[\sigma]$ Is the allowable stress and

$$\frac{M}{W_z} = 32MPa < [\sigma] \tag{3}$$

The maximum stress is less than the allowable stress, which means that the design is reliable.

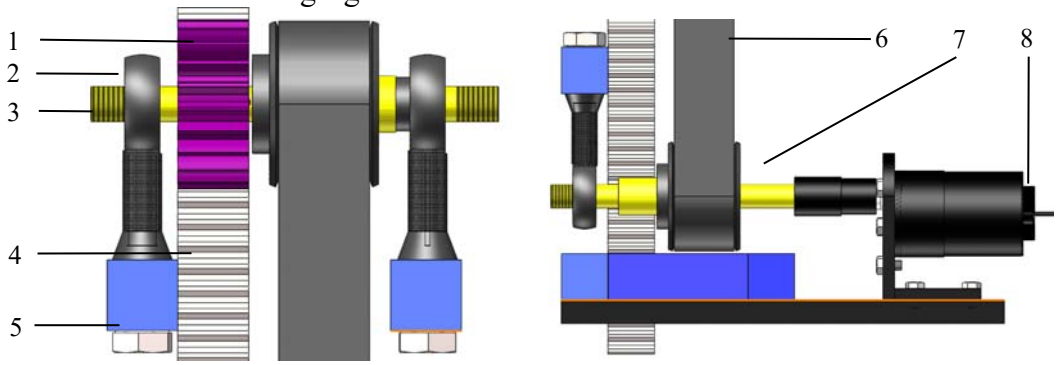
The material of the Pinion keeps the same as the Rack. The parameters of the Rack and Pinion are designed as follows:

Table 2. Rack and pinion design results

Parameters	Design Results
Module of gear	2mm
Number of teeth	15
Pitch-circle diameter	30mm
Addendum	2mm
Reddendum	2.5mm
Circular pitch	6.28mm
Outside diameter of gear	34mm
Pressure angles	20 degrees

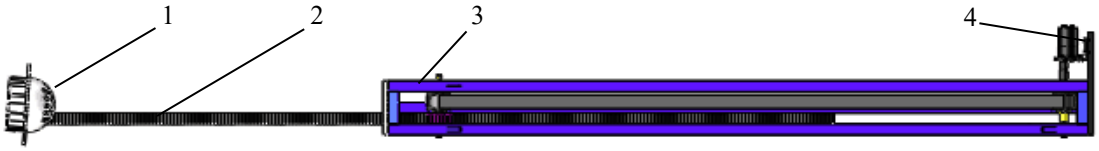
3.2 Assembly Mechanism.

All the components and the assembly are 3D modeled by Pro/E software and simulated. The design results are as following figures.



1-Pinion 2-Bearing 3-Shaft 4-Rack 5-Frame 6-Belt 7-Synchronous Wheel 8-Motor

Fig 1. Sub-assembly of transmission mechanism



1-Cutter 2-Rack 3-Frame 4-Motor

Fig 2. 3D Assembly model

4. Prototype Development

The prototype is built and picking experiments are conducted. It has three operating modes: ascending mode, positioning mode and descending mode.

Ascending mode: At the beginning of picking, the worker selects this mode, and the motor will drive the rotation of synchronous wheel. Through the rotation of the shaft, the pinion can drive the rack to move upwards.

Positioning mode: When the rack ascends to the altitude at which the fruits need to be picked, the worker selects this mode and the motor will stop. In this way, the rack is seized up by the pinion and fixed at a stable altitude. Then the worker can operate the cutter to clamp the fruit on the ground.

Descending mode: After the above steps, the worker selects this mode, and the motor will drive the reverse rotation of the synchronous wheel. Through the rotation of the shaft, the pinion can drive the rack to move downwards. As a result, the fruit can be pulled down by the pulling force.

(a)Prototype (before stretching out) (b) Prototype (after stretching out) (c) Picking experiment
Fig 3. Prototype Verification

5. Summary

The research on electric telescopic fruit picker in this paper has mainly two achievements: firstly, the worker can pick fruits with the device on the ground; secondly, the device can automatically stretch out and draw back to pick fruits, which enhances the efficiency.

To be more specific, the device has the following advantages:

(1) The workers can complete the picking operations on the ground with no need to climb the tree, which guarantees their safety;

(2) The fruits at a very high altitude which cannot be reached by workers can be picked by the device, which avoids the waste of fruits;

(3) As the cutter has a relatively large radius and can be changed according to the fruit to be picked, the device is suitable for the picking of most fruits at a high altitude and the altitude can be changed based on the actual conditions. That is to say, the device has rather few limitations on fruit type and a wide range of operation altitudes;

(4) The tree and branches will not be greatly damaged due to man-made causes;

(5) The device has a simple structure, low costs and is easy to operate and maintain.

Compared with other fruit harvesting pickers, the device proposed in this paper is convenient to take along and has a simple appearance and a wide range of application. With a mechanized and semi-automatic function, strong operability and low costs, it is suitable for picking many kinds of fruits, thus saving the labor, reducing the workload of orchard workers and possessing a broad application prospect in the field of fruit harvesting.

Acknowledgements

This work was supported by innovation training project of Hexing College of Hubei University (DC201816).

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