Research and Design of a Portable Traction-type Solo Montanic Picking Device and Fruit Conveying System

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Abstract. In order to improve the degree of mechanical engagement in orchard harvesting, we design a "solo, light-weight and low energy-consuming" picking platform based on artificial picking and realize automatic picking, conveying and packing with the aid of artificial apple recognition. The design of a fruit conveying system for the platform should take mechanical damage theory into full account, realize the transfer from picking position to bins using a 3-level conveyer and make a detailed and comprehensive design and analysis on the spatial layout, physical dimensions and working principle of each unit in the whole device. The results of prototype experiment show that by simulating actual conditions, when the fruit pass rate is lower than 90/min, the damage rate is less than 5%. The maximum harvest per hour is 5400. The proposed design meets the requirements of actual operation.

1. Introduction

Fruit picking is the main factor that restricts the development of fruit industry. Mechanized harvest can free labor, improve production efficiency and reduce production costs [1]. At present, the most widely-used picking methods in practice are mainly harvest machines which separate fruit trees from fruits by means of vibration or impact, large automatic picking platforms and harvesting robots. However, due to the large population in China and numerous hills in the south, fruit trees are planted on dense terraces [2]. It is always impossible to carry out large mechanical operations. So in this paper, we design a portable traction-type solo montanic picking device, to provide a reference for the research on terraced orchard picking equipment.

2. Overall Structure and Working Principle

2.1. Composition

The portable traction-type solo montanic picking device mainly includes a traction and folding frame, an auxiliary fruit picking device, a fruit conveying pipe and a fruit stacking system[3], as shown in Fig.1. Among them, the fruit stacking system mainly includes an automatic lifting device and a passive slowdown and equalizing device, as shown in Fig.2.

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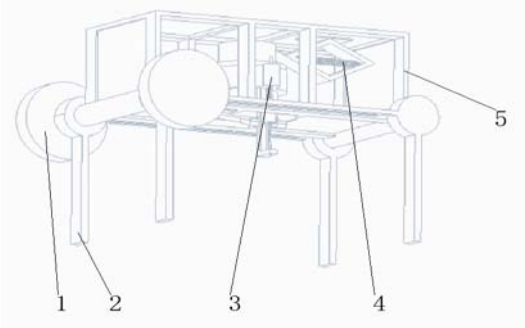


Figure 1. Schematic Diagram of the Traction-type Solo Montanic Picking Device.
1. Wheel; 2. Folding support; 3. Passive slowdown and equalizing device; 4. Automatic lifting device; 5. Frame

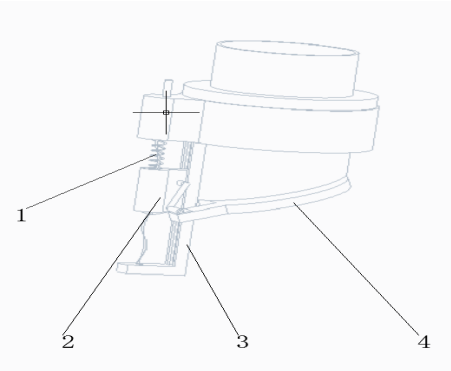


Figure 2. Automatic Bin Stacking System
1. Rebound spring; 2. Rebound slider; 3. Track; 4. Speed brake.

2.2. Drive and control system

The drive and control system includes 12V DC motor, 30,000mAh lithium battery, 10,000 mAh lithium battery, various port control switches, circuit, radar rangefinder, laser detector and stepping motor, etc[4]. The picking parts and lifting parts of the portable traction-type solo montanic picking device are driven by power. Rotary stacking is driven by gravity. DC gear motor and stepping motor are used to supply power respectively. The power circuit and control circuit in each part constitute the drive and control system of the platform.

Secondly, the laser detector controls the stepping motor through Arduino control panel and drives the rotatory cutter to cut through a transmission device, thus completing the harvest of a single apple on high.

Thirdly, by sensing the distance, the radar rangefinder controls the DC gear motor through an MCU [5] and controls lifting by controlling the deformation of a rhomboid mechanism.

2.3. Working principle of the platform

As shown in Figure 3., according to the repeated action process of an orchard worker in solo work (picking, bending over, stacking and moving) [6], we design a piece of mechanical equipment to assist the picking device, sectorial pipe collecting and conveying device, automatic stacking device and flexible and mobile supports to achieve these four functions, minimize the workload of workers and improve their work efficiency.

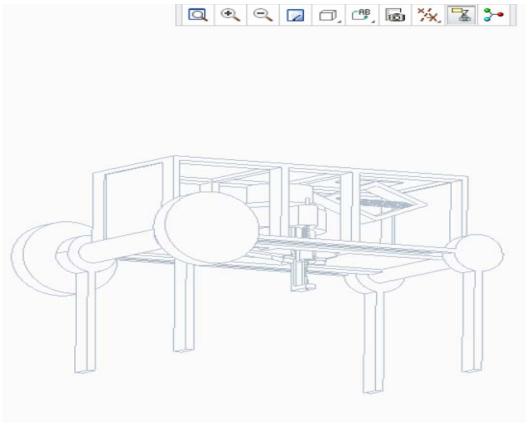


Figure 3. 3D Design Drawing of the Traction-type Solo Montanic Picking Device

Since the growth height of fruits is divided into two types, accessible by human hands or inaccessible by human hands directly, so the device can be divided into two working modes, too[7]. Through human eye recognition, the manipulator connected to a long rod can cut fruits on high automatically. Fruits can be transferred into the orifice of a 1.2-meter-high middle pipe, along the upper pipe and transmission device. The upper pipe is made of light and soft materials. Thus, it can move within two meters around the orifice of middle pipe easily together with the picking device. The middle pipe adopts a sectorial collection design, for pickers to adjust the tilt angle manually independently. The middle sector is connected to the upper pipe through thread gluing. Apples at an accessible high to human hands can be directly put into the middle sectorial collection area, without the need of a manipulator [8]. Fruits pass the middle sectorial collection area in proper order, finally enter an apple stacking device through the lower flexible pipe that can be stretched and folded, fixed by a rhombus lifting device. The stacking device reverses the flip at the bottom through the weight of the apple, drives the plunger shaft, as well as the gear mechanism on it to complete stacking steering. Controlling by radar ranging below, it drives the motor built in the rhombus lifting device, monitor and control the distance between the bottom of stacking device and fruit plane in real time, making the bottom of stacking device keep a distance of 5cm from the highest apple [9], so that apples can be placed neatly, without getting damaged in the final free falling.

At the end of picking, pickers stop working. The supports can be folded into the shape of a trolley case, as shown in Figure 4. The bin can be roughly divided into picking manipulator and upper pipe storage area, lower pipe folding & storage area and fixation area in stacking device [10], so that pickers can move the device to the next place.

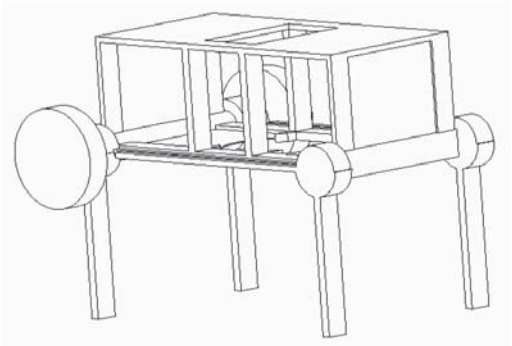


Figure 4. 3D Design Drawing of the Traction-type Solo Montanic Picking Device (Folded)

2.4. Main technical indicators

In view of the current varieties of traditional terraced fruit trees in China, the row spacing is 3-4m, the plant distance is 3-4m, the height of trees is 3-4m and the crown breadth is 4-5m in orchards. According to the characteristics of orchard planting, using CATIA software ergonomics analysis, the parameters of the portable traction-type solo montanic picking device are identified as in Table 1.

Table 1. Main Parameters of the Portable Traction-Type Solo Montanic Picking Device

Parameter	Value
Overall dimensions when folded (L×W×H)/mm	540×360×600
Unfolded operating range in horizontal direction/mm	1200-600
Unfolded operating range in vertical direction/mm	1500-4000
Bin dimensions /mm	500×300×300
Adjustable range of stacking device/mm	0-300
Working height of manipulator/mm	1800-4000
Average transmission speed of fruits in the pipe/(m• s^{-1})	0.5
Output speed of apples from the stacking device/(m•s^{-1})	0.1
Collision speed between fruits in the bin /(m• s^{-1})	0.2
Harvest time of a single fruit by the manipulator/s	0.5
The number of fruits harvested per minute in continuous work	80

3. Design of Key Parts

3.1. Picking manipulator

A picking manipulator is a device that exempts people from climbing a ladder or branch to pick fruits on high. The picking manipulator is mainly composed of the upper work area and lower light pipes, which are 500 mm long each and joined together with thread, as shown in Figure 5.

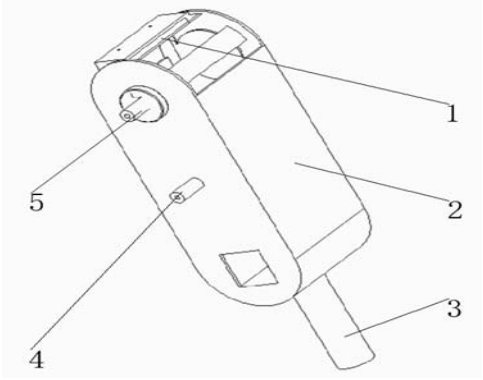


Figure 5. The Structural Diagram of the Picking System
1. Blade; 2. Manipulator shell; 3. Connector of flexible rod; 4. Laser detector; 5. Steering gear

The joint between pipes allows the work area to touch apples growing within the 2-4m easily. The front work area is composed of a rotary 3-tooth cutter with slipknot, capsule shell and supporting power control facilities. The slipknot between the vertical and horizontal planes of the cutter can ensure the movement of blade [11]. When the blade turns to lower position, due to gravity, it can drop down to ensure that the apple flows into the lower pipe more smoothly. The inside of capsule shell has an increasingly higher slope, which can force the blade to change from vertical direction to a direction perpendicular to the vertical direction, when turning from lower to upper positions. The extruded plane on it has a sharp blade, which forms a shear force with the blade and cut through the apple branch.

There are parallel laser rays 10cm below the cutting point [12]. When the rays are cut off by the apple in it, they will control the stepping motor to drive the cutter to rotate by 120° and shear the branch. While the rotary motion and arc on the surface of apple can press the branch during movement, so that the apple can shake up and down in a small range on the branch easily. Therefore, the lower surface of blade is tangent to the apple from time to time, so that the final cutting point will cling to the surface of fruit and finish precision cutting.

3.2. Automatic Bin Stacking System

The main purpose of automatic bin Stacking System is to prevent fruits from heaping up in the pipe orifice, colliding with and damaging each other when entering the bin. It is mainly composed of lower passive rotary part and lower adaptive lifting gear, as shown in Figure 6.

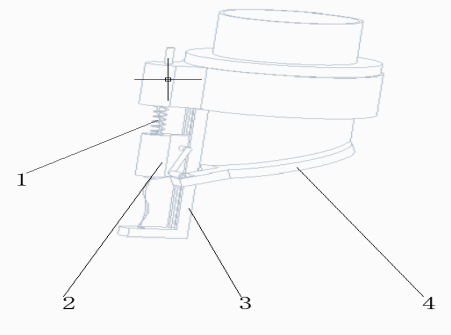


Figure 6. Automatic Bin Stacking System
1. Rebound spring; 2. Rebound slider; 3. Track; 4. Speed brake

In the passive rotary device, relying on the weight of apple, the lower flip levers up the slider above the screw and drives the upper small gear to rotate. The small gear occludes with the large gear fixed onto it, so that the small gear and its screw can have circular motion around the pipe. In this way, when an apple is output, it will rotate once. The previous apple will not affect the output of the next. When a layer of fruits is filled and the lower micro radar detector detects that the minimum distance between apples and the device is less than 7cm, it will send a signal to the upper motor to drive the screw rod to control the rhombus lifting drive to stretch, so that the device can rise as a whole and subsequent apples can be stacked in the upper layer of bin and fill the upper space.

3.3. Folding traction support system

The folding traction support system is designed to facilitate long distance movement of the overall device. It mainly includes picking manipulator and upper pipe storage area, lower pipe folding & storage area and fixation area in stacking device, as shown in Figure 7.

When long distance movement is required, first of all, store the upper pipe and its manipulator into a storage box, then pull out the flexible rod on the top of box, turn the whole box by 90°, remove pins that fasten the legs, fold and connect the legs, so as to fold the whole box into the shape of trolley case, to facilitate long distance movement.

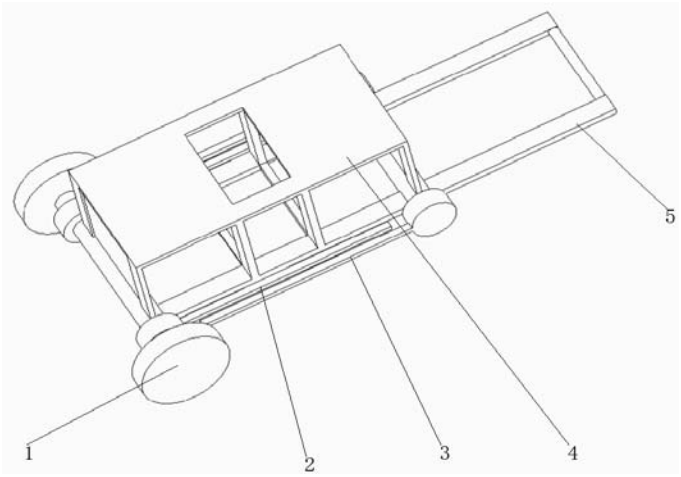


Figure 7. Schematic Diagram of the Folding Structure of Overall Frame
1. Wheel; 2. Rear leg of folding support; 3. Front leg of folding support; 4. Body; 5. Flexible rod

4. Experiment and Result Analysis

4.1. Experimental conditions and materials

To validate the conveying performance of fruit conveying system and feasibility of fruit conveying scheme, we carried out a fruit conveying experiment on the system. The location of experiment was College of Mechanical and Electrical Engineering, Northwest A&F University. The apples for experiment were purchased on the market. The variety was Fuji. The origin was Yan' an, Shaanxi.

4.2. Experimental method

The whole device includes upper, middle and lower pipes and the lower is a folded pipe. Obviously, when the pipe is stretched to the maximum, it is most adverse for the protection of apples. So when the lower pipe is stretched to the maximum and the upper and middle pipes have smooth transition, it is most adverse to the protection of apples. Therefore, the upper flexible pipe and middle plastic pipe are divided into four states: vertical at the same time, 30°, 45° and 60° to the vertical direction.

When fruits are conveyed, to simulate the most severe conveying environment for field operation, all fruits are input from orifice of the upper pipe in three modes: 0/min, 90/min and 120/min. The experimental process is shown in Figure 8.



Figure 8. Fruit Conveying Experiment

4.3. Experimental results and analysis

The fruit conveying experiment is conducted in 12 groups. The resulting conveying efficiency and damage rate in each group are shown in Table 2.

The experimental results show that the closer the conveyor is to lower speed and vertical, the higher conveying efficiency it has. At 60/min and 90/min, apples won't collide in the pipes. The damage rate was extremely low, about 0.5% to 0.5%. When two fruits are input quickly, i.e., at 120/min, the damage rate will rise significantly and increase with the increase of pipe slope, but always above 5%. The picking speed of fruits should be less than 90/min, in case economic benefits are affected.

Table 2. Results of the Fruit Conveying Experiment

No.	Tile Angle of Pipes/°	Fruit Placement Frequency/pc/min	Damage Rate/%	Conveying Speed /(m•s^{-1})
1		60	1.43	1.22
2	30	90	1.46	1.17
3		120	5.2	1.21
4		60	1.59	1.45
5	45	90	1.72	1.39
6		120	5.7	1.44
7		60	2.3	1.71
8	60	90	3.1	1.69
9		120	6.9	1.76
10		60	3.3	1.96
11	90	90	4.2	2.04
12		120	8.7	1.99

5. Conclusion

(1) For small terraced orchards that are unfavourable for large mechanical operation, we propose a portable auxiliary device based on solo picking and make a detailed design of fruit conveying system.

(2) An innovative rotary cutting and picking method is proposed for the upper picking manipulator, to achieve quick and efficient picking of apples on high. For lower stacking, we propose a gravity steering mode, greatly reduce energy consumption caused by rotary stacking and minimize energy carrying.

(3) By simulating actual harvest conditions, the apple conveying results show that when the input speed of apples is lower than 90/min, the damage rate is less than 5% and meets the requirement of actual production. A maximum of 5400 apples can be harvested per hour. This speed has exceeded the actual speed found at which people touch apples. It is unnecessary to improve the slowdown and stacking device, in case the previous and next fruits collide in the pipes.

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