# MECHANIZATION DEVICES FOR HANDLING BRANCHES IN MODERN ORCHARDS
/
## 现代果园枝条机械化处理装置

**Li Hui [1,2], Yang Xin [1*], Yang Aiqian [2]**    [1]

[1] College of Mechanical and Electrical Engineering, Hebei Agricultural University, Baoding, 071000/China;
[2] Research Institute of Mechanical and Electronic, Hengshui University, Hengshui, 053000/China;
*E-mail: yangxin@hebau.edu.cn*

**ABSTRACT**

*In most parts of China, pruned branches in orchards are still treated manually. In order to reduce the intensity and labor cost, this paper provides a mechanical solution for branches collection, which mainly includes the gathering device, picking device, and smashing device. A simulation platform with a human-computer interaction was developed in Matlab. It can set optimization goals based on human practical experience and optimize the main influencing parameters, and both the gathering device and the picking device achieve the design simulation on this platform. Furthermore, this method helps to quickly obtain the data of key components in the core device. Firstly, the shape of the Slide-way shell of the gathering device can be obtained quickly through different gathering ranges. Secondly, a group of angle and motion trajectory of the picking device with lower height was obtained from the simulation design. Furthermore, the performance of the improved picking device under four different laying conditions was tested. The results showed that, under R=38-42 r/min and V=0.80-0.95 m/s, the success rate of the picking device was 94.2%, 92.5%, 61.0% and 30.8%, respectively. The field test demonstrated that there are no significant differences between the simulated test results and practice test results.*

**摘要**

*在中国的大部分地区，果园里修剪过的树枝仍然是主要依靠人工处理的。为了降低劳动强度和管理成本，本文提出了一种机械化处理枝条的方案，主要包括聚拢装置、捡拾装置和粉碎装置。在 Matlab 中开发了具有人机交互功能的仿真平台。它可以根据人类的实践经验设定优化目标，对主要影响参数进行优化。聚拢装置和捡拾装置均在此平台上实现了模拟仿真运动。该方法有助于快速获取核心设备中关键部件的数据。首先，通过聚拢范围的不同，能够快速获得聚拢装置滑道壳体上滑道的形状。其次，能够得到了一组合理的捡拾装置的角度和运动轨迹。此外，还对改进后的拾取装置在四种不同铺设条件下的性能进行了试验。结果表明，在 R=38~42r/min、V=0.80~0.95m/s 条件下，采摘装置的成功率分别为 94.2%、92.5%、61.0%和 30.8%。场地试验结果表明，模拟试验结果与实际试验结果无显著差异。*

**INTRODUCTION**

Apple is one of the most widely planted fruits in northern China. In 2018, the planting area was about 2.54 million ha and the fresh output reached 39 million tons, accounting for more than 40% of the world. Growers general prune branches twice per year, and a large amount of branch residues are produced in orchards *(Abdallah et al., 2011)*.

These residues from orchards or forests are renewable biomass resources that can be recycled to compensate for the shortage of fuel in remote areas *(Leszek et al., 2014; Paweł et al., 2016)*. In China, the branch residues scattering on the ground is commonly manual picking-up, which is labor-intensive and costly *(Bussemaker et al., 2015)*.

This traditional operation mode urgently needs new technological support to handle with these residues. In order to meet the requirements of growers, there is an urgent need for innovative mechanized devices to replace the traditional manual way.

---

[1] *Hui Li, Ph.D. Stud.; Xin Yang, Prof. Ph.D.; Aiqian Yang, Lecturer*

Agricultural machinery manufacturers from Europe, America, Canada and Australia have developed several types of shredders. They are one of the commonly used machines for mechanization treatment of orchard pruning residues *(Dyjakon, 2018a)*.

The agricultural machinery technology of residues collection is relatively mature *(Dyjakon, 2018b; Gong et al., 2020)*. The general residues collection mainly includes collecting, picking-up, feeding, smashing and recovering *(Guerra et al., 2018; He et al., 2016)*.

At present, various types of gathering devices have been developed and widely used in pastures. An aggregator was used to convert the scattered straw into straight stripes for drying and recycling *(Florian et al., 2014)*. For example, Rolabar 256 rotary drum tedder and WR10 series of finger wheel tedder of the United States, RT 13 finger wheel tedder of Italy and Liner series horizontal rotary rake of Germany *(Kumar et al., 2015)*. In addition, engineers from Whitlands developed a tool harrow with adjustable angle, which was mainly used to recycle vineyard pruning residues. RX series rotary brush gathering device produced by Fa.ma of Italy was installed on the tractor head, which can also collect pruned grape-vines scattered on the ground to the center of the row *(McEniry et al., 2008)*.

*Luigi et al., (2018)* reported that the research team of Poznan University in Poland cooperated with a local fruit growing farm to develop a collection device with three rotating iron sheets, which is similar to the reinforcement version of rotary brush. However, there are few studies on the structural design and working principle of the gathering device for branch residues, as well as the evaluation and test of its performance.

In order to make full use of these pruning residues, some growers suggest collecting them by machine and then storing them to substitute some wood as fuel or energy sources *(Pari et al., 2018)*. A round baler was developed and tested by the New Holland Company, which proved the feasibility of using baler to collect pruning residues.

*Florian et al, (2014)* designed and tested a new mini-baler for hilly areas to recover vineyard pruning residues that were inaccessible to traditional tractors *(Naujoks B., 2011)*. However, the test performance and mechanical design of the baler picking system are rarely mentioned and specified.

*Yu et al., (2018)* tested the picking performance index of optimal parameter combination of the spring-finger cylinder harvester for green forage and corn stalks.

*Xu et al., (2016)*, optimized the primary parameters of spring finger picker according to the biophysical characteristics of peanut stalks *(Qiang et al. (2018)) (Ren et al., 2020)*. However, there are few researches on the spring finger picking mechanism for hard-stalk crops collection, and the application of other pickers on hard stem crops is also rare. In view of the differences between soft-straw crops and hard-stalk crops, the design of picking mechanism for pruning residues is carried out.

The main purpose is to design a mechanical device for collecting branch pruning residues by comprehensively considering the critical influence factors of collecting and picking-up. The objectives are design and analysis of the critical parts of the whole machine, including gathering device, picking device and smashing device. Then, the picking performance of the machine is tested under different laying conditions of branch residues. The relations between the laying orientation of branches and the picking success rate are evaluated.

## MATERIALS AND METHODS

A mechanized processing device suitable for pruning branches in orchards is studied. The process mainly includes gathering, picking-up, smashing and collecting. The structural design and parameters optimization of both gathering and picking-up are completed with human-computer interaction to improve the efficiency of design.

## STRUCTURE DESIGN

The whole machine is applied for processing the branches in orchard, which mainly includes gathering device, picking device, smashing device and a collection bin with a filter, as shown in Figure 1 *(Spinelli et al., 2014)*. Among them, the gathering device collects the branches in the middle of rows; the picking device picks the residues on the ground, and the smashing device works in an almost close shell. It not only uses hammer claw to crush most of the residues, but also uses rotary blade mechanism to cut branches with large diameters. The collection bin with filter is used to collect residues or collect them in bags or containers.
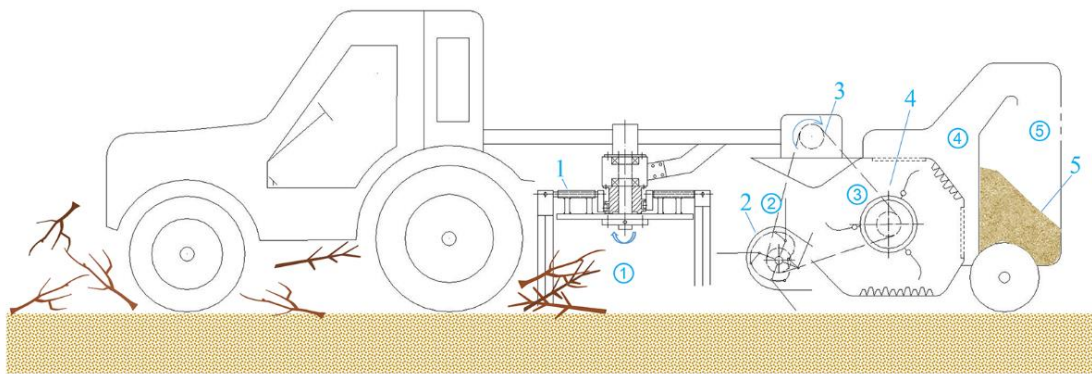
**Fig. 1 - Machine structure**

*1, gathering device; 2, picking device; 3, driving system; 4, smashing device; 5, collection bin.*

*① to ⑤ represent the handling steps of branch residues. The pruning residues of the orchard branches are collected at position ① and the smashed residues are finally collected in the dustbin at position⑤.*

### Gathering device

The gathering device is mainly composed of hydraulic motor, rotary chassis, shell with track and a set of crank connected machinery, as shown in Figure 2. Hydraulic power comes from a tractor. A set of implement mechanism fixed on the rotary chassis mainly includes swing crank, swing connecting rod, axle sleeve, spring teeth and crank bearing. The axle sleeve is welded on the surface of the chassis. The swing connecting rod is connected with a spring teeth through the shaft sleeve, and the other end is connected with the swing crank. A bearing is installed on the other end of the swing crank and it slides in the track of the shell. The movement trajectory of the spring teeth is limited by the slide-way shape of the shell. It makes complex movements, including rotary movement around the hydraulic motor and swing movement around the axle sleeve.
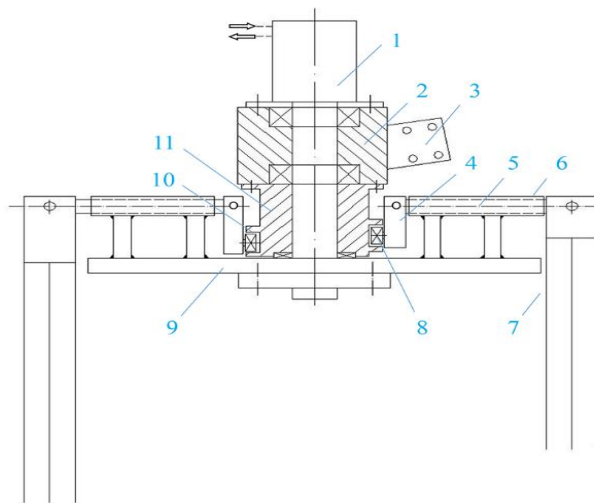
**Fig. 2 - The structure of gathering device**

*1. Hydraulic motor; 2. Upper end shell; 3.Fixed end; 4, Swing crank; 5. Swing connecting rod; 6. Axle sleeve; 7.Spring-tooth combination; 8. Crank bearing; 9. Rotation chassis; 10. Track; 11. Shell with slide-way*

In order to facilitate the kinematic analysis of the collecting mechanism, its structure schematic is drawn as Figure 3. Where, α1 represents the rotation angle of spring tooth around point O; β1 represents the swing angle of spring tooth around line OK; P1, P2 and P3 of the diagram represent the dividing point of different actions during the whole collecting process. P1P2, P2P3 and P3P1 represent the collecting phase, departing phase and return to original phase respectively. Based on the kinematic analysis, a mathematical model of collecting mechanism is established and an optimization design platform is developed. The whole running process of the collecting mechanism is simulated on the platform, as shown in Figure 4. The data value of the mechanism is optimized by means of human-computer dialogue and expert experience under the guidance of parameter optimization *(Xiudan, 2015; Ye et al., 2013)*.

Slide-way shell is a core component of the gathering device. The track shape controls the implement mechanism movement and impacts the effect of collecting directly. According to the swing angle of spring teeth in different processes, an effective slide-way (point J) is obtained by using the optimization design platform, as shown in Figure 5 *(Tao et al., 2016)*.
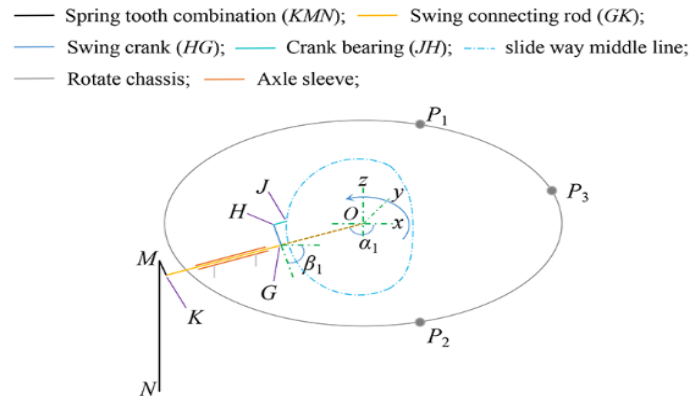
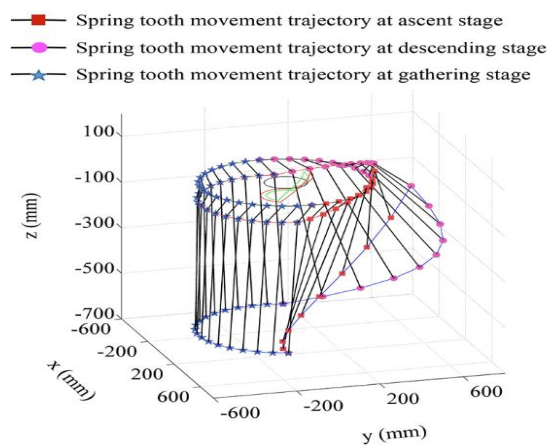**Fig. 3 - The motion schematic diagram of gathering device**

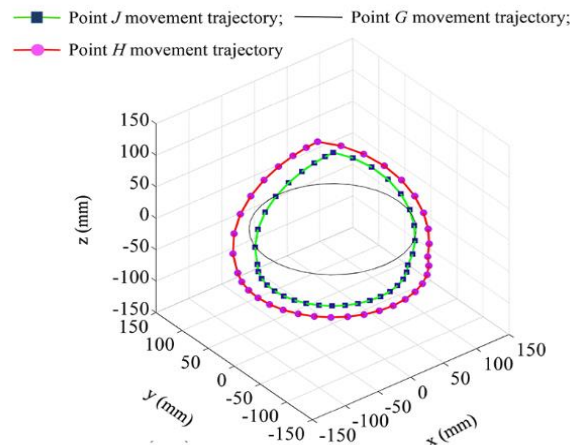**Fig. 4 - The static movement simulation trajectory of gathering device**

**Fig. 5 - The slide-way middle line (green) of the shell of gathering device**

### *Picking-up device*

The working principle of the spring finger-cylinder picking device is described as follows, mainly consists of link_1, crank_2, spring fingers_3, central axis_5, cam disk_6, and guard plate_7. In Figure 6, link_1 makes a circular movement around point O. At the same time, the spring finger_3 follows link_1 to make circular movement and make swing movement under the limitation of cam disk_6. The mechanism adjusts the posture of the spring finger by changing the shape of the cam disk to meet the requirements of picking pruning residues.

Link_1 rotates one full turn around point O. The entire cycle is divided into five phases: stacking, lifting, transporting, feeding, and separating and recovering according to the attitude of the spring finger in space. F represents the action force of spring finger to branch pruning residue_4. F1 and F2 are F-branch forces in the horizontal direction and the vertical direction respectively. The coordinate system defines point O as the center of the mechanism. x is the horizontal coordinate axis and y is the vertical coordinate axis. ΔA1B1C1, ΔA2B2C2, ΔA3B3C3, ΔA4B4C4 and ΔA5B5C5 are different positions of the picking mechanism in the running process. A1-A5 represents the top end of the link; B1-B5 represents the top end of the crank, and C1-C5 represents the top end of the spring finger. H is the distance between A3C3 and the ground in the lifting phase, that is, the picking height of the device.
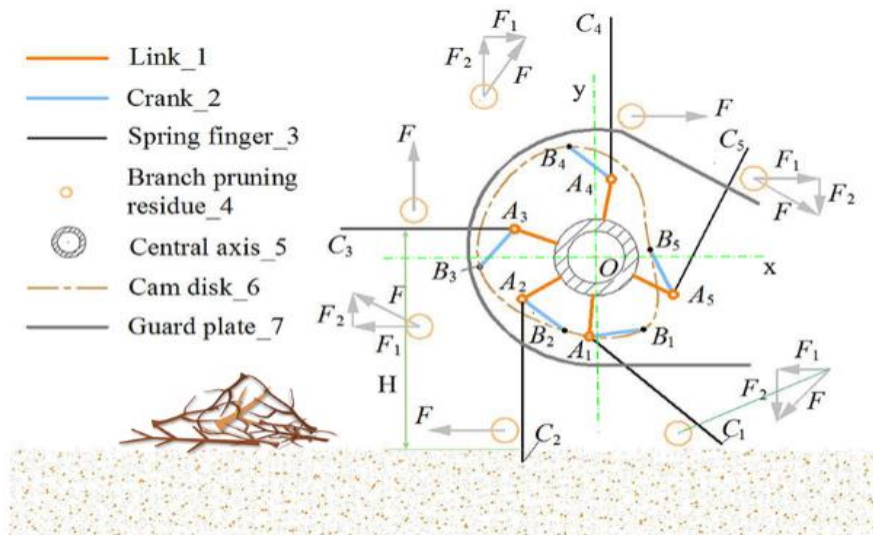
**Fig. 6 - Kinetic analysis of spring finger picking device**

The kinetic analysis results of the picking device are shown in Table 1.

**Table 1**

**Kinetic analysis of each phase in an entire cycle**

| Each phase | Branches forced | | | | α (°) | β (°) | |
|---|---|---|---|---|---|---|---|
| | $F1$ (N) | | $F2$ (N) | | | Starting | Ending |
| Stacking | x- | ↑ | y- | ↓ | $α_1 = \angle A_1OA_2$ | $A_1C_1$ (45°) | $A_2C_2$ (90°) |
| Lifting | x- | ↓ | y+ | ↑ | $α_2 = \angle A_2OA_3$ | $A_2C_2$ (90°) | $A_3C_3$ (180°) |
| Transporting | x+ | ↑ | y+ | ↓ | $α_3 = \angle A_3OA_4$ | $A_3C_3$ (180°) | $A_4C_4$ (270°) |
| Feeding | x+ | ↓ | y- | ↑ | $α_4 = \angle A_4OA_5$ | $A_4C_4$ (270°) | $A_5C_5$ (315°) |
| Separating and recovering | | | | | $α_5 = \angle A_5OA_1$ | $A_5C_5$ (315°) | $A_1C_1$ (45°) |

Note that the picking-up device rotates clockwise as positive direction. *A* represents the rotation angles of the middle central axis; *β* represents an angle between the spring finger and the horizontal coordinate axis in the coordinate system; '↑' represents the gradual increase, and '↓' represents the gradual decrease. In the coordinate system, 'x+' represents the positive direction of the x-axis; 'x-' represents the negative direction of the x-axis; 'y+' represents the positive direction of the y-axis, 'and y-' represents the negative direction of the y-axis.
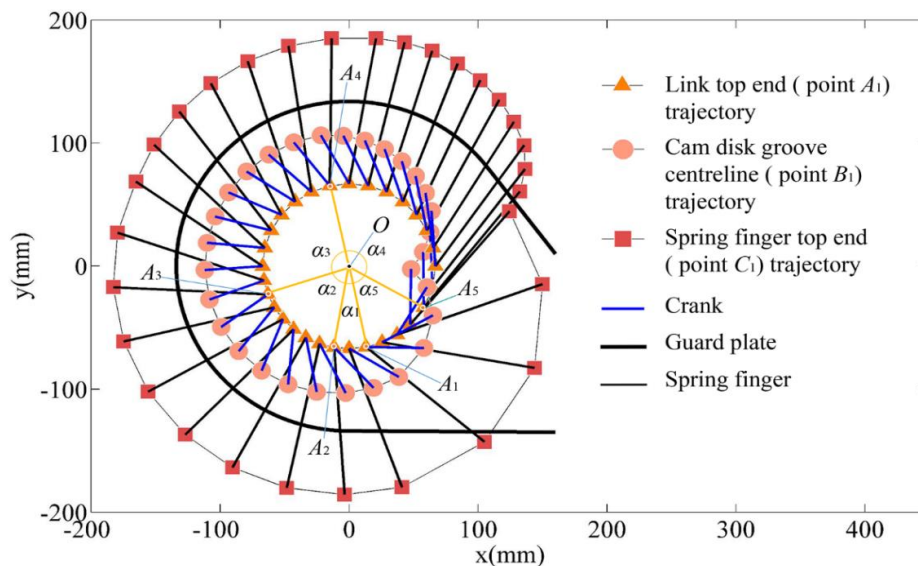


**Fig. 7 - Static simulation movement trajectory of the picking device**

In Figure 7, the picking device runs clockwise in its positive direction throughout the cycle. Based on the structure of the picking device, the mathematical model is established, the static programs are written and the simulation platform is developed in Matlab environment. In this platform, human-computer interaction is employed to optimize the primary parameters of the mathematical model.

As shown in the optimization objective, the angle (β) of the spring finger contacting with scattering branches is maintained in the range of 40°- 50° in the stacking stage. The angle α1 should be decreased as much as possible to avoid 'congestion'. In the lifting phase, α2 should maintain a minimum angle so as to obtain a low picking height. In the transporting phase, the spring finger should reach the vertical attitude soon to strengthen the followed feeding. In the feeding phase, α4 should be increased to prolong the distance of feeding *(Ye et al., 2013)*. In the separating and recovering phase, the spring finger should be pulled out gradually along the vertical direction of the top of the guard plate to avoid clamping branches. As shown in Table 3, according to these optimization objectives, the main structural parameters of the picking device are optimized on the movement trajectory simulation platform.

*Smashing device*

The smashing device is the main part of the machine that is used for crushing pruning residues. It mainly includes the driving end, smashing part, chipping part, shell, filter net, fixed blade and main shaft. In order to meet the resistance required for crushing residues, chain drive is selected. The hammer claws of the smashing mechanism are arranged alternately, so that the machine can crush the residues smoothly, as shown in Figure 8 *(Yu et al., 2018)*.

The chips on the right side are used to handle the branches manually with a large diameter and feed into the crushing cavity from entrance to become particles. The chip function consists of a stationary blade fixed on the shell and a moving blade installed on a heavy rotating base *(Zhao et al., 2018)*.

The rotating base can also be used as a counterweight, thereby improving the crushing ability of the hammer claw only the inlet and outlet are reserved in the shell. These repeated hammering residues become smaller particles than the filter mesh in the shell cavity, and then enter the container chamber along the discharge pipe.
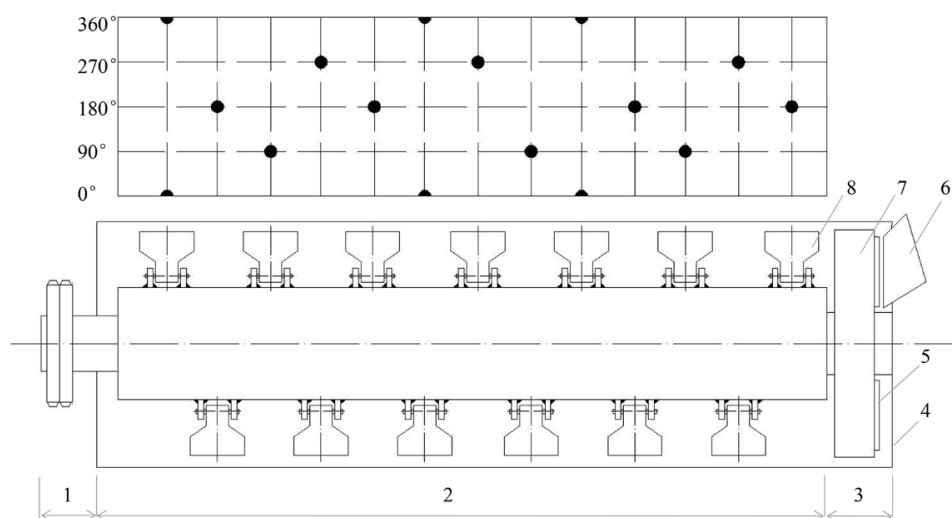


**Fig. 8 - Smashing device**
*1. Driving end; 2. Smashing part; 3. Chipping part; 4. Smashing shell; 5. Moving blade; 6. Entrance for chipping;*
*7. Rotation base; 8. Hammer claw combination*

**OPEN FIELD TEST**
*Picking-up device prototype test*

In order to test the performance of the picking device, a baler with spring finger picking is used to collect the ground residues. To evaluate the influence of different postures of branches on the ground, four conditions are set.

Figure 9 (a-d) shows disordered branches, horizontal branches and longitudinal branches, including the first contact between the treetop and the spring fingers or the first contact between the thick stem of the branch and the spring fingers.

**Fig. 9 - The improved picking device is tested under four different conditions.**
*(a-d) showed the disordered state of the exchange direction between the end of canopy and thick stem of trunk,*
*the transverse laying state perpendicular to the straight road, and the laying state along the straight road respectively*

*Collection efficiency*

The success rate of branch residues collection is defined as the percentage of branch residues successfully collected in the total weight. The picking success rate is determined by Eq. (1).

$$\eta_2 = \frac{W - W_r}{W} \times 100 \tag{1}$$

Where, $\eta_2$ is the picking success rate; $W_r$ is the weight of residues loss, and $W$ is the weight of total branch residues scattered on the ground in each test.

Under these four different conditions, branch pruning residues are collected 14 times. According to the plan, three tests are carried out in each case, and two of them fail because the tractor is out of control. The average picking success rate is calculated as follows:

$$\eta_{2'} = \frac{\sum_{k=1}^{n} \eta_{2(k)}}{n} \tag{2}$$

where, $\eta_{2'}$ is the average picking success rate, and $k$ is the number of test for each condition and $n$=3.

The test results are shown in Table 5.

**RESULTS AND DISCUSSION**
**OPTIMIZATION PARAMETERS RESULTS**

Based on the simulation technology, the moving trajectory of the gathering device and the picking-up device are simulated and optimized. The optimization results are obtained as shown in Table 3 and Table 4.

**Table 3**

**Optimized parameters of gathering device**

| Parameter | Unit | Symbol | Value |
|---|---|---|---|
| Length of swing crank | *mm* | $L_{GH}$ | 80 |
| Depth of crank bearing | *mm* | $L_{HJ}$ | 30 |
| Length of swing connecting rod | *mm* | $L_{GK} = L_{OK} - L_{OG}$ | 300 |
| | *mm* | $KM$ | 100 |
| Spring tooth | *mm* | $KN$ | 650 |
| | ° | $\angle MKN$ | 35 |
| | ° | $P_1 P_2\ (\alpha_1)$ | -90-60 |
| Rotation angle of the rotating chassis (clockwise rotation on the left) | ° | $P_2 P_3\ (\alpha_1)$ | 60--25 |
| | ° | $P_3 P_1\ (\alpha_1)$ | -25--90 |
| | ° | $P_1 P_2\ (\alpha_1)$ | -90-120 |
| Rotation angle of rotating chassis (rotate counterclockwise on the right) | ° | $P_2 P_3\ (\alpha_1)$ | 120--155 |
| | ° | $P_3 P_1\ (\alpha_1)$ | -155--90 |
| Angle of between x axle and swing crank | ° | $\beta_1$ | -45-45 |

**Table 4**

**Optimization parameters of picking-up device**

| Structural parameters | Coordinate (*mm*) | $\alpha$ (°) |
|---|---|---|
| $OA_1 = OA_2 = OA_3 = OA_4 = OA_5 = 67$ mm,<br>Length of the crank_2 = 45 mm,<br>Length of the spring finger_3 = 120 mm,<br>$\angle B_1A_1C_1 = \angle B_2A_2C_2 = \angle B_3A_3C_3 = \angle B_4A_4C_4 = \angle B_5A_5C_5 = 39°$ | $A_1$ (11.36, -65.98) | $\alpha_1 = 25°$ |
| | $A_2$ (-16.45, -64.95) | $\alpha_2 = 50°$ |
| | $A_3$ (-61.36, -26.91) | $\alpha_3 = 86°$ |
| | $A_4$ (-29.07, 60.36) | $\alpha_4 = 147°$ |
| | $A_5$ (60.72, -28.32) | $\alpha_5 = 52°$ |

**EXPERIMENT RESULT OF PROTOTYPE**

This experiment is carried out in an open field located at BoYo Agriculture Equipment Co. LTD in China (114.71°N, 38.01°W). Firstly, four straight strips of 15 m (L) long and 1.8 m (Wi) wide are drawn. Secondly, the weighed branch residues are laid on the ground and the height is maintained at 100-250 mm. Secondly, the weighed tree dregs are placed on the ground, and the height is maintained at 100-250mm. In addition, the auxiliary equipment is Dongfanghong-MF604.The laser tachometer (SW-6234C) is used to measure the rotation speed of the picking device. The scales (Edberg NK/HP and G&G/Shuang Jie SW-6234C) are used to measure the total weight of branch residues before the experiment and that of weight losses after the experiment. Total three tests are carried out for each condition and the time (T) of each test is recorded. The results are shown in Table 5.

**Table 5**

**Data analysis of the practical experiments**

| Branch conditions | t (sec) | L (mm) | V=L/t (mm/s) | R (r/min) | Weight (kg) | | $\eta_2$ (%) | Average $\eta_{2'}$ (%) |
|---|---|---|---|---|---|---|---|---|
| | | | | | W | Wr | | |
| Figure 9a | 15.8 | | 950 | | | 0.84 | 94.4 | |
| | 16.5 | | 910 | | | 0.57 | 96.2 | 94.2 |
| | 17.2 | | 870 | | | 1.21 | 91.9 | |
| Figure 9b | 17.0 | | 880 | | | 1.30 | 91.3 | |
| | 16.1 | | 930 | | | 0.79 | 94.7 | 92.5 |
| | 16.3 | 15000 | 920 | 40±2 | 15±0.2 | 1.28 | 91.5 | |
| Figure 9c | 17.9 | | 840 | | | 4.72 | 68.5 | |
| | 16.9 | | 890 | | | 7.32 | 52.2 | 61.0 |
| | 17.0 | | 880 | | | 5.65 | 62.3 | |
| Figure 9d | 16.5 | | 910 | | | 9.22 | 38.5 | |
| | 16.0 | | 940 | | | 11.30 | 24.7 | 30.8 |
| | 15.8 | | 950 | | | 10.62 | 29.2 | |

The optimization results in Table 3 show that the effective working range of spring teeth is extended from original 180° to 210°, but the range of returning is shortened to 65°, which is more conducive to bring the branches to the middle of orchard rows. In order to verify the practicability of the picking mechanism simulation platform, a rectangular baler with spring finger is used as the test carrier. The measured data are input into the man-machine dialogue window to optimize these parameters and can get α2, α4, and a lower H as shown in Table 4. The central line equation of the core part cam disc is obtained on the platform window. It can use MATLAB to process the data of cam disk. According to the data processing results, the cam disk is redesigned and its supporting parts are improved and get a new cam disk, as shown in Fig 9. Finally, the picking device is tested in an open field.

Table 5 shows the test comparison of four pruning residues scattering on the ground. When the rotation speed of the picking device is 38~42r/min and the moving speed is 0.80~0.95m/s, the success rate of picking in Figure 9a is 94.2%, which proves the effectiveness and potential of the method. The picking success rate of Figure 9b is close to Figure 9a under the same V and R. The reason is that the spring finger starts to push the transverse laid branches forward, finally stack together in a disordered state. Figure 9c and Figure 9d have a lower picking success rate of 61.0% and 30.8% respectively. Figure 9c shows that the branches moved to the side of the picking device and there were some branch losses.

Figure 9d makes it difficult to pick because the thick stem of the branch is inserted directly into the gap, which makes the spring finger unable to operate the branch effectively. The experiments confirmed that if the thick end of branch stems is drilled into the bottom of the picking device, most of them will be lost. Therefore, the situation of Figure 9d should be avoided.

## CONCLUSIONS

In this paper, the mechanized treatment path and related equipment of orchard pruning residue are studied, and a human-computer dialogue design method is used to optimize the main devices structural parameters of mulching machine. Through the field test about the optimized picking-up device, the practicability and accuracy of the design method are verified. The conclusions are as follows. Through the simulation platform about the gathering device, a group of parameters are obtained quickly and accurately. The effective working range of spring teeth is extended and the return phase of spring teeth are shortened in the entire gathering period, which is more suitable to the gathering branches operation. Similarly, a set of suitable spring finger angle and lower picking-up height of spring finger are obtained quickly and accurately from the simulation platform about the picking-up device. A prototype of picking-up device is developed according to the optimized parameters. The success rate of the prototype is 94.2% under the optimal conditions. Field experiments show that the improved device can significantly improve the success rate of pruning residues picking that can meet the requirements of operation.

This study showed a promising and proper mechanical solution or idea for collecting residues in orchard. The machine will be tested in an orchard and applied to the farm in the future. The research results can provide basic data for the design of harvesting machine to collect pruning residues and the human-computer interaction design method can also be applied to other mechanisms.

## ACKNOWLEDGEMENTS

## REFERENCES

[1]     Abdallah R., Auchet S., Méausoone P.J., (2011), Experimental study about the effects of disc chipper settings on the distribution of wood chip size. *Biomass and Bioenergy*, 35(2): 843–852. https://doi.org/10.1016/j.biombioe.2010.11.009

[2]     Bussemaker M.J., Day K., Drage G., Franjo C., (2015), A Value Chain Optimization Model for a Biorefinery with Feedstock and Product Choices. *Computer Aided Chemical Engineering*, 37(June): 1883-1888. https://doi.org/10.1016/B978-0-444-63576-1.50008-X

[3]     Dyjakon A., (2018a), Harvesting and baling of pruned biomass in apple orchards for energy production. *Energies, MDPI, Open Access Journal*, 11(7): 1-14. RePEc:gam:jeners:v:11:y:2018:i:7:p:1680-:d:154835

[4]     Dyjakon A., (2018b), The influence of the use of windrowers in Baler machinery on the energy balance during pruned biomass harvesting in the apple orchard. *Energies, MDPI, Open Access Journal,* 11(11): 1-15.

[5]     Florian A., Arkadiusz D., Paweł F., Leszek R., (2014), Conception of Machine for Pressing Branches with Pruning Fruit Tree. *Journal of Research and Applications in Agricultural Engineering*, 59(2): 5-9.

[6]     Gong I., Lee K., Kim J., Min Y., Shin K., (2020), Optimizing Vehicle Routing for Simultaneous Delivery and Pick-up Considering Reusable Transporting Containers: Case of Convenience Stores. *Appl. Sci.* 10, 4162. DOI: 10.3390/app10124162

[7]     Guerra S.P.S., Oguri G., Denadai M.S. et al., (2018), Preliminary trials of the BioBaler working in Brazilian eucalypt plantations. Southern Forests, 80(2): 131-135. https://doi.org/10.2989/20702620.2017.1292441

[8]     He L., Fu H., Karkee M. et al., (2016), Effect of fruit location on apple detachment with mechanical shaking. *Biosystems Engineering*, 49(16): 293-298. https://doi.org/10.1016/j.ifacol.2016.10.054

[9]     Kumar I.M.S., Kumar D.T.R.H., (2015), Design and Development of Agricultural Waste Shredder Machine. International Journal of Innovative Science, *Engineering & Technology,* 2(10): 164-172.

[10] Leszek R., Arkadiusz D., Florian A., Piotr F., (2014), Problems with deriving the fruit tree pruned biomass for energy use. *Agricultural Engineering*, 3(157): 157-167. DOI:10.14654/IR.2014.151.068

[11] Luigi P., Alessandro S., Angelo D.G., Antonio S., Enrico S., (2018a), Influence of chipping system on chipper performance and wood chip particle size obtained from peach pruning. *Biomass and Bioenergy,* 112(January): 121-127. https://doi.org/10.1016/j.biombioe.2018.01.002

[12] McEniry J., O'Kiely P., Clipson N.J.W. et al., (2008) The microbiological and chemical composition of silage over the course of fermentation in round bales relative to that of silage made from unchopped and precision-chopped herbage in laboratory silos. *Grass and Forage Science,* 63(3): 407-420. https://doi.org/10.1111/j.1365-2494.2008.00645.x

[13] Pari L., Suardi A., Frąckowak P. et al., (2018b) Two innovative prototypes for collecting pruning biomass: Early performance tests and assessment of the work quality. Biomass and Bioenergy, 117: 96-101. https://doi.org/10.1016/j.biombioe.2018.07.010

[14] Paweł F., Florian A., Grzegorz W., Michał S., Arkadiusz D., Luigi P., Alessandro S., (2016), A prototype machine for harvesting and baling of pruning residues in orchards: first test on apple orchard (Malus Mill.) in Poland. *Journal of Research and Applications in Agricultural Engineering*, 61(3): 88-93.

[15] Naujoks B., (2011), Project final report. ETICA EU Project, (December): 1-89.

[16] Qiang M., Jiang L., Hang Z., Yamei W., Qian G., Ling Z., (2021), Design and simulation Analysis of Trussing Jujube Remnant Crusher. *Journal of Agricultural Mechanization Research,* (1): 101-108.

[17] Ren D., Zhongxian Z.H., Jiadong L., Qikai M., Bowei S., Lili T., (2020), Kinematics Analysis on Elastic Tooth of Horizontal Rotating Rake. *Mechanical Engineer*, 3: 1-4.

[18] Spinelli R., Lombardini C., Pari L., Sadauskienec L., (2014), An alternative to field burning of pruning residues in mountain vineyards. *Ecological Engineering*, 70: 212-216. https://doi.org/10.1016/j.ecoleng.2014.05.023

[19] Tao X., Yongzhe S., Lianxing G., Xudong Z., Changyi L., Zhixia L., (2016), Spring-finger Peanut Pickup Mechanism Based on Two-stage Harvest. *Transactions of the Chinese Society for Agricultural Machinery*, 47(3):90-97,111

[20] Xiudan M., (2015), Development Situation of Raker Machine in Foreign Countries.7-10.

[21] Ye B.L., Liu A., Yu G.H., Luo C.X., (2013), Parameters optimization with human-computer interaction method and experiment of vegetable seedling pick-up mechanism. *Nongye Jixie Xuebao/Transactions of the Chinese Society for Agricultural Machinery*, 44(2): 57-62.

[22] Yu Z.H., Huai S.C., Wang W.M., (2018) Leakage rate and optimization of working parameters for cylinder pickup collector based on spring-finger trajectory. *Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering*, 34(4): 37-43.

[23] Zhao Z., Huang H., Yin J., Simon X. Yang, (2018), Dynamic analysis and reliability design of round baler feeding device for rice straw harvest. *Biosystems Engineering*, 174: 10-19. https://doi.org/10.1016/j.biosystemseng.2018.06.014