KINEMATIC SIMULATION AND EXPERIMENTAL ANALYSIS OF A ROLLER BRANCH PICKING MECHANISM

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辊式枝条捡拾机构运动学仿真与试验分析

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ABSTRACT

Apple tree branches have the physical characteristics of high cellulose content and high elasticity, and the use of traditional soft straw pickers will miss a large number of branches. It is necessary to design a picking mechanism that adapts to the physical characteristics of fruit tree branches. In the treatment of branches in modern orchards, the picking mechanism is an important part of the picking device. The success rate of picking directly affects the processing performance of the whole machine. To improve the picking rate, the roller branch picking mechanism is studied. The trajectory of the roller picking and the stress state of the branches are analyzed, and five main factors affecting the picking effect are obtained, i.e. the position relationship between the rotation center of the picking roller and the feeding roller, inclination angle of the steel teeth, the effective working length, the speed and the forward speed of the machine. A mathematical model is established to obtain the static and dynamic motion trajectories of the roller picking mechanism are obtained by using Matlab. Taking the analysis results of influencing factors as the optimization goal, the picking trajectory of the mechanism is simulated to obtain a set of non-inferior solutions. A roller branch picker is manufactured according to the parameter values and tested in the field, and the picking rate can reach 91%.

摘要

苹果树枝条具有纤维素含量高、弹性大的物理特性，使用传统的软秸秆类捡拾器进行作业会造成大量枝条漏捡的现象，因此需要设计一种适应果树枝条物理特性的捡拾机构。在现代果园枝条处理过程中，捡拾机构是机器捡拾装置中的重要组成部分。捡拾成功率直接影响着整机的处理性能。为了提高捡拾率，对辊式枝条捡拾机构展开研究。分析了对辊式捡拾运动轨迹以及枝条受力状态，得到 5 项影响捡拾效果的主要因素，分别是捡拾辊与喂入辊的旋转中心相互位置关系、刚性齿的倾斜角度、有效作业长度、转速和机器前进速度。建立数学模型，使用计算机编制 Matlab 程序获得对辊式捡拾机构的静态运动轨迹和动态运动轨迹。以影响因素分析结果作为优化目标，对机构的捡拾轨迹进行了仿真试验，获得一组非劣性解。按照参数值制造出一款对辊式枝条捡拾器并进行了田间试验，捡拾率达 91%。

INTRODUCTION

China has long been the forefront of fruit production in the world. According to incomplete statistics, only in 2020, the apple planting area exceeded 2 million hectares, and the output was as high as 41 million tons, accounting for more than 50% of the world's total output *(Georges et al., 2014)*. With the decline of traditional apple orchard planting modes, China's modern apple orchard cultivation modes have developed rapidly, and the technical means applied are becoming more and more advanced. To ensure apple quality, apple trees need to be pruned several times throughout the year. Pruning has always been a time-consuming, laborious and high-intensity labor process, resulting in about 20% of the management cost of human, material and financial resources *(He et al., 2017)*. Mechanization of pruned branches can reduce investment costs. Picking the scattered branches on the ground and centralizing them is an important step for mechanization.

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In the harvesting process of ordinary straw crops, the performance of the picking and feeding device directly affects the operational efficiency and quality of the entire machine *(Flick et al., 2019)*.

According to the differences in the biological form and physical characteristics of different crops, different picking methods are the basis of research *(Mou, 2015)*. The key influencing factors, such as the height, position, angle, movement speed and rotation speed of picking, involved in the mechanized treatment of branches are mainly studied. To evaluate the impact of different factors on the picking process of apple branches, its motion trajectory is simulated. A branch picking test platform similar to a sport equipment ball picking mechanism is developed that can adjust the specific parameters of the influencing factors and implement uninterrupted adjustable functions.

Many international agricultural equipment companies have developed picking mechanisms for different crops, with roller picking mechanisms being the majority. For example, the Panther suspended single-roll picking crusher produced by the Niubo manufacturing company in Spain is capable of picking most of the branches. The picking structure of the Super Max suspended roll picking crusher produced by the Niubo Manufacturing Company in Spain consists of the upper and lower rollers. From the axial point of view, the upper roller is forward. During operation, the upper and lower rollers rotate to each other. The lower roller realizes the picking function, and the upper roller realizes the auxiliary feeding function, which greatly reduces the phenomenon of flying out to the outside after the single roller collides with branches *(Velázquez-Martí and Fernández-González, 2019)*. The suspended single-roll picking crusher from the Mirco Bros Pty Company in Australia has added a "steel fork" structure. Its function is to stack the branches on the ground forward, and after reaching the height of single-roll picking, the branches are fed into the crushing chamber.

The TR200 traction branch crushing and collection integrated machine produced by Facma Company in Italy has spiral arrangement of picking teeth, which makes the branch picking movement concentrate towards the center of the spiral *(Amirante et al., 2016)*.

The EDY CHIPPER branch crushing and collection integrated machine produced by the CAEB International Manufacturing Company in Italy was equipped with the gathering device on both sides of the body, increasing the picking width of the machine. This device can concentrate scattered branches on the ground to the center of the orchard rows, making them staggered and intertwined, and the involvement of each other is more conducive to picking *(Adamczyk et al., 2014)*.

The PRB 1.75 circular branch packaging machine jointly developed by the agricultural engineering industry organization in Poland, the orchard farm in Przybroda and the Polish Agricultural University, also applied a roller picking structure *(Frąckowiak et al., 2016)*.

The self-propelled branch crusher jointly developed by IHI Shibaura Co., Ltd., Uji Manufacturing Co., Ltd. and Civil Agricultural Machinery Co., Ltd. in Japan, has its picking part composed of screw augers, which can collect pruned branches to the center in advance.

The main purpose of this study is to design a roller structure picking device suitable for branches, aiming to establish a simulation platform for multi-factor influence on the picking motion of roller. Under the design requirements considering the physical characteristics of apple branches, the influence of the main influencing factors on the picking motion trajectory can be tested to obtain an optimal set of design parameters.

MATERIALS AND METHODS

Characteristics and formation mechanism of the double roller picking and feeding trajectory

Characteristics and posture of picking and feeding trajectories

The double-roller picking and feeding mechanism needs to meet the conditions of continuous conversion of picking, feeding and separating in the picking process of branches. It also needs to be designed taking into account the physical characteristics of apple branches. Generally, the roller picking and feeding mechanism adopts a structure of rotatory roller welded steel teeth, and is composed of the upper part and the lower part. The upper rotatory roller structure is the auxiliary feeding roller, and the lower is the picking roller. Observing the picking of the machine, first, the steel teeth pile up the scattered branches on the ground towards the forward direction of the machine. When the height is higher than the center position of the rotary roller, the branches begin to be lifted off the ground and transit to feeding. During the picking process, a small part of the branches slips off due to being close to the top of the teeth. Some of the branches are assisted by the feeding roller for feeding, as shown in the trajectory 1 in Fig.1.

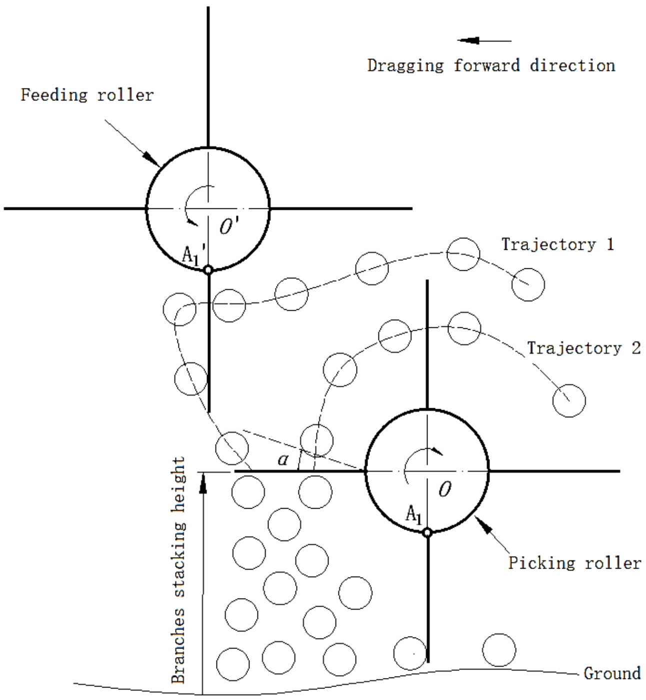

Fig. 1 - The motion trajectory of the double-roller picking and feeding mechanism

Compared with the single-roll picking and feeding mechanism, the double-roll picking and feeding mechanism has added an auxiliary feeding roller to improve the feeding performance and the picking and feeding rate *(Dyjakon et al., 2018)*. The trajectory of the roller steel teeth maintains a perfectly circular shape, showing a regular transverse spiral with different speeds. The picking postures are determined by the spatial angle of the steel teeth. The angle size should comprehensively consider the field obstacle avoidance performance, picking performance and separating performance, shown as α in Fig. 1. The comprehensive analysis shows that the main factors that affect the characteristics of static and dynamic motion trajectories are the position relationship between the rotation centers of the picking roller and the feeding roller, inclination angle of steel teeth, effective working length, speed and machine forward speed. The analysis is as follows:

(1) The position relationship between the rotation centers of the picking roller and the feeding roller

The position between the picking roller and the feeding roller has direct effect on the feeding of branches. When the picking roller mechanism picks up the branches and lifts them off the ground, some branches slip off the tooth tips due to high rotational speed, forming a parabolic trajectory in space and being thrown out. The feeding roller will assist the picking roller in preventing the slipping branches from moving in a parabolic manner, and then feed the branches to the inlet of the crusher. The position between the picking roller and the feeding roller should pay attention to the following points: ① The center position of the feeding roller mechanism should not be too high, and it is best to have the steel tooth tips staggered and "engaged"; ② The center position of the feeding roller should not be too forward or backward relative to the center position of the picking roller mechanism. Excessive forward will effectively prevent the phenomenon of "throwing branches", but will affect the feeding effect. Excessive backward will improve the feeding performance, but will not effectively prevent the phenomenon of “throwing branches".

(2) Inclination angle of the steel teeth

The steel tooth angle of the picking roller is deflected upwards, while that of the feeding roller is deflected downwards. The steel teeth rotate with the roller. The double-roller rotates oppositely in the direction shown in Fig. 1. The steel teeth are arranged axially to form an effective bite angle to feed the branches to the inlet of the crusher. If the inclination angle of the steel teeth is too large, the bite angle formed will be greater, which will affect the separation between the branches and the steel teeth, and may lead to mandatory "cutting" of the branches, causing the machine to instantly overload and stop.

(3) Effective operating length of the steel teeth

The steel teeth are welded onto the roller, and the protective plate is placed on the surface of the roller, but does not contact with the roller and affect its rotation. The length of the steel teeth beyond the radius of the protective plate is the effective operating length.

The effective operating length of the steel teeth is related to the workload, including the rotation radius during picking and feeding operations, as well as the size of machine energy consumption. If the rotation radius is too large, it will raise the picking height, increase the difficulty of picking and increase energy consumption; if the rotation radius is too small, it will directly lead to a narrowing of the feeding window and a decrease in the ability to treat branches.

(4) Rotation speed of the picking and feeding rollers

Since the center position of the picking roller and that of the feeding roller are not on the same vertical coordinate, it is difficult to ensure that each pair of steel teeth is always in the "bite" state during operation in terms of their rotation speed ratio. In the motion simulation trajectory, only when the steel tooth tip of the picking roller and that of the feeding roller intersect in motion can the feeding performance be effectively improved. The solution is to set the initial installation position, so that after a pair of teeth is engaged, the relative position of the power end is fixed for installation. The ratio of the rotation speed of the feeding roller to that of the feeding roller is adjusted to (1.1-1.2):1.

(5) Forward speed

The forward speed of the double-roller picking mechanism should match the processing capacity of branches, and it is also directly affected by the driving force. The forward speed during operation is adjusted based on the branches in the orchards. If the branches are large, the forward speed is reduced; otherwise, the forward speed is increased. If the amount consumed in an instant is large or the diameter of branches is too thick, it is likely to overload and stop.

Dynamic analysis during the picking and feeding process

The double-roller branch picking and feeding mechanism mainly consists of two parts: the picking roller and the feeding roller, which cooperate with each other to complete the picking. Dynamic analysis of the entire mechanism helps to design and optimize the parameters of the mechanism. Fig. 2 shows that the mechanism is roughly up and down, with the feeding roller located in front and above the picking roller. The picking roller rotates clockwise and the feeding roller rotates counterclockwise. Among them, A_1B_1, A_2B_2, A_3B_3 and A_4B_4 represent four different positions during the movement of the steel teeth on the picking roller. Similarly, $A_1'B_1'$, $A_2'B_2'$, $A_3'B_3'$ and $A_4'B_4'$ represent four different positions during the movement of the steel teeth on the feeding roller. The speed of the two is set according to the kinetic simulation analysis involved later in the design. During operation, the steel teeth on the picking roller rotate at high speed and contact with the scattered branches on the ground. The branches are pushed forward and begin to move forward, pile up, and finally interlace to form a cluster of branches. When the pile reaches a certain height, it will be lifted off the ground by the steel teeth. When leaving the ground, the branches are subjected to the external force exerted by the steel teeth. At the same time, other branches in the stacked state, like the piled rice stalks, have a greater implicated effect, moving forward and upwards *(Lei et al., 2015)*. At this time, the feeding roller rotates counterclockwise, and the steel teeth on the central axis begin to contact the branches, applying backward and downward forces to the branches, making them move towards the entrance of the crushing chamber. After reaching the entrance, they are simultaneously subjected to the dual action of the steel teeth on the feeding roller and the picking roller, moving towards the inside of the crushing chamber. Then the branches are fed into the chamber for crushing, so as to realize picking and feeding.

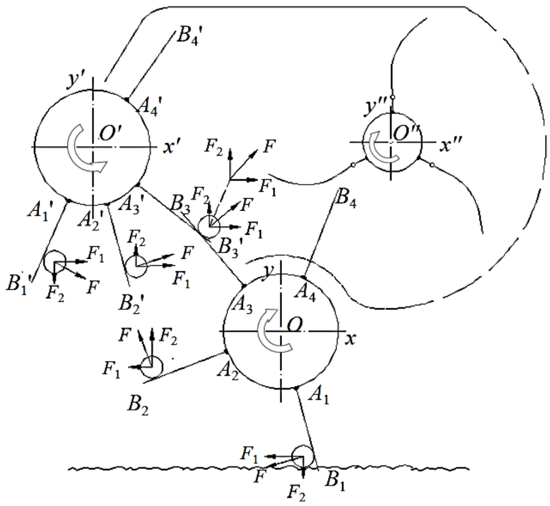

Fig. 2 - Kinetic analysis of the double-roller picking device

In the picking process of branches, the picking roller mainly completes stacking branches, lifting off the ground, conveying backwards, separating branches and returning to the initial state. The feeding roller mainly assists in completing feeding, conveying backwards, separating branches, and returning to the initial state. Under the simultaneous actions, a trajectory is formed from the ground to the air, moving towards the direction of the crushing chamber. As shown in Table. 1.

Table 1

Kinetic analysis during the picking process of branches

Operating parts	Actions	Stress analysis of branches		Space position of the spring teeth
		Horizontal direction F_1	Vertical direction F_2	
Picking roller (Coordinate System *xOy*)	Gather branches	“-”gradually↓	From“-” to“+” gradually↑	A_1B_1~A_2B_2
	Lift off the ground	From“-”to “+”gradually↑	“+”gradually↑	A_2B_2~A_3B_3
	Convey backwards	“+”gradually↑	“+”gradually↓	A_3B_3~A_4B_4
	Branch separating	None	None	A_4B_4~A_1B_1
Feeding roller (Coordinate System*x'Oy'*)	Auxiliary feeding	“+”gradually↑	“+”gradually↑	$A_1'B_1'$~$A_3'B_3'$
	Convey backwards	“+”gradually↓	“+”gradually↑	$A_3'B_3'$~$A_4'B_4'$
	Separating branches	None	None	$A_4'B_4'$~$A_1'B_1'$

Note: "↑" indicates increase; "↓" indicates decrease; "-" indicates the negative direction of the coordinate system axis; "+" indicates the positive direction of the coordinate system axis, and "none" indicates no change.

MATHEMATICAL MODEL OF THE DOUBLE-ROLLER PICKING AND FEEDING MECHANISM

Most fruit tree branches have a high content of wood fiber, a large number of branches, and a certain degree of elasticity *(Nona et al., 2014; Zeng and Chen, 2019)*. Compared with soft straw crops, it is less prone to bending under impact and plastic deformation in compression *(Lei et al., 2022; Yuan et al., 2002)*. In view of these common physical characteristics, a branch picking device with a rigid structure is designed, that is, a double-roller picking and feeding device. It has two parts, the picking roller and the feeding roller, which are installed up and down, and each has irregular shaped steel teeth. The picking roller is located at the lower part of the device, mainly completing the picking, lifting the branches from the ground. The feeding roller is located on the upper part of the device, mainly realizing the function of auxiliary feeding, i.e. feeding the branches to the inlet of the crushing chamber. The entire process is simulated using Matlab software. In the design process of the seedling retrieval mechanism of the automatic transplanting machine, Chen *et al (2013)* used Matlab to optimize the structural parameters to achieve precise clamping. *Mao et al (2013)* and *Liao et al (2015)* studied the kinematic analysis of seven-pole and double-five-pole planting mechanisms respectively, and also solved the mathematical model with the help of Matlab to simulate the motion trajectory and structural optimization. Based on Matlab simulation technology, the structure and working principle of the double-roller picking and feeding device are studied, and a mathematical model is established. Based on Matlab, the software is simulated and analyzed dynamically.

According to the analysis results, the main factors affecting the picking effect are determined, and the main influencing parameters are analyzed by single-factor. Establishing a simulation design platform for branch picking, the main factors are optimized to obtain a set of non-inferior solution combinations. The picking and crushing part of the double-roller branch crusher mainly consists of a frame, a power system, a picking and feeding device, a crushing device, auxiliary support wheel assembly, and a suspension system. Among them, the picking and feeding device mainly includes the transmission end, picking and feeding mechanism, frame, etc. The picking and feeding mechanism is mainly composed of the picking roller, feeding roller, separating assembly, and supporting assembly. The roller is equipped with rigid teeth arranged in a spiral shape, with the axis as the distribution center axis, uniformly distributed, and rotating in opposite directions with *O* and *O'* as the rotation centers, as shown in Fig. 3. The rigid teeth are welded to the central axis. The separation of rigid teeth and branches is accomplished by the separating assembly. The functions of the double-roller picking and feeding device are to accumulate the branches scattered between the rows of orchards, lift the branches off the ground and convey them backwards. During the conveying process, the central axis of the feeding roller rotates oppositely with that of the picking roller. After the rigid teeth of the feeding mechanism contact the branches, it assists it to convey backwards until it enters the crushing chamber for auxiliary feeding.

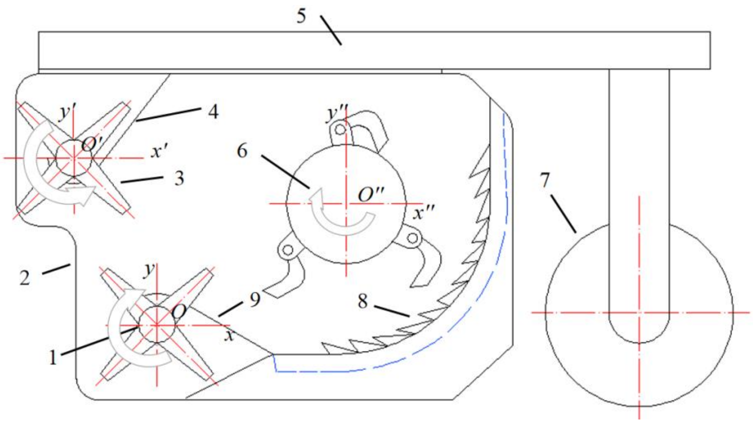

Fig. 3 - Simplified diagram of the branch crusher of the double-roller picking and feeding mechanism

1. Picking roller; 2. Shell; 3. Feeding roller; 4. The feeding roller assembly; 5. Frame; 6. The crusher; 7. Supporting wheel; 8. Serrated blades and filter assembly; 9. The picking roller assembly

(1) The picking roller

The force analysis during the picking process of branches: the picking mechanism rotates clockwise with point *O* as the rotation center. Taking point *O* as the dot, the coordinate system *xOy* is established. A_1, A_2, A_3 and A_4 are four different locations in the operation of point *A*. The coordinates of point *A* are (x_{JA}, y_{JA}); ω_A represents the angular velocity; *t* represents time, and R_{JA} represents the radius of rotation at point *A*. The relationship between ω_A, t, and α_A is as follows:

$$\alpha_A = \omega_A \times t \tag{1}$$

The location of point *A*is as follows:

$$x_{JA} = x_{J1} + R_{JA} \times \cos(\alpha_A)$$
$$y_{JA} = y_{J1} + R_{JA} \times \sin(\alpha_A) \tag{2}$$

B_1, B_2, B_3 and B_4 are four different locations in the operation of point B. The coordinates of point B are (x_{JB}, y_{JB}); N_A is the rotation speed, rad/s, and R_{JAB} is the distance from point A to point B, shown as follows:

$$\alpha_B = \alpha_A + N_A \times \frac{\pi}{180} \tag{3}$$

$$x_{JB} = x_{JA} + R_{JAB} \times \cos(\alpha_B)$$
$$y_{JB} = y_{JA} + R_{JAB} \times \sin(\alpha_B) \tag{4}$$

When the tractor runs forward, V_A represents the speed; L_A represents the running distance, and the dynamic coordinates of point A are as follows:

$$x_{DA} = x_{JA} - L_A$$
$$y_{DA} = y_{JA} \tag{5}$$

The dynamic coordinates of point B are as follows:

$$x_{DB} = x_{JB} - L_A$$
$$y_{DB} = y_{JB} \tag{6}$$

(2) The feeding roller

The feeding roller mechanism takes point *O′* as the center of rotation and counterclockwise rotation as the positive direction. Then the coordinates of point *O′* in the *xOy* coordinate system are (x_{w1}, y_{w1}). A_1', A_2', A_3' and A_4' are four different locations in the operation of point A'. The coordinates of point A' are (x_{wA}', y_{wA}'); ω_A' is the angular velocity, and t is the time, shown as follows:

$$\alpha_A' = \omega_A' \times t \tag{7}$$

$$x_{WA}' = x_{W1} + R_{WA'} \times \cos(\alpha_A')$$
$$y_{WA}' = y_{W1} + R_{WA'} \times \sin(\alpha_A') \tag{8}$$

B_1', B_2', B_3' and B_4' are the positions in the operation of point B'. The coordinate of point B' are (x_{wB}', y_{wB}'); N_A' is the rotation speed, rad/s; $R_{wA'B'}$ is the distance from point A' to point B', shown as follows:

$$\alpha_{B'} = \alpha_{A'} + N_{A'} \times \frac{\pi}{180} \tag{9}$$

$$x_{WB}' = x_{WA'} + R_{WA'B'} \times \cos(\alpha_B')$$
$$y_{WB}' = y_{WA'} + R_{WA'B'} \times \sin(\alpha_B') \tag{10}$$

When the tractor is running forward, V_A' represents the speed; L_A' represents the running distance, and the dynamic coordinates of point A' are as follows:

$$\begin{aligned} x_{DA}{}' &= x_{WA}{}' - L_A{}' \\ y_{DA}{}' &= y_{wA}{}' \end{aligned} \tag{11}$$

The dynamic coordinates of point B' is as follows:

$$\begin{aligned} x_{DB}{}' &= x_{WB}{}' - L_A \\ y_{DB}{}' &= y_{WB}{}' \end{aligned} \tag{12}$$

RESULTS AND ANALYSIS

Computer Virtual Simulation of Motion and Parameter Optimization

Based on the kinematic analysis of the double-roller picking and feeding mechanism, and considering the changes in the motion trajectory of the rigid teeth in space in actual operation, a computer program is developed using Matlab to simulate the motion, as shown in Fig. 4.

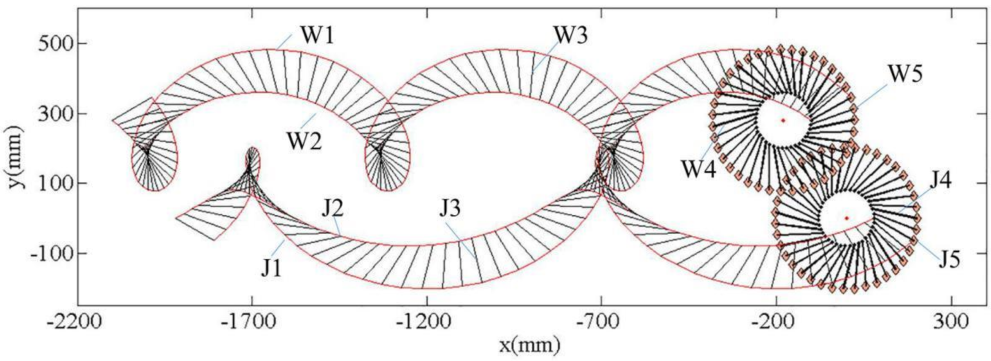

Fig. 4 - Static and dynamic trajectories of the double-roller picking and feeding mechanism

J represents the picking roller mechanism, where $J1$ is the dynamic motion trajectory of the steel teeth tip; $J2$ is the dynamic motion trajectory of the top of the central rotation axis; $J3$ is the space posture of the dynamic motion trajectory of the steel teeth; $J4$ is the space posture of the static motion trajectory of the steel teeth; $J5$ is the static motion trajectory of the steel tooth tip. W represents the feeding roller mechanism, where $W1$ is the dynamic motion trajectory of the steel tooth tip; $W2$ is the dynamic motion trajectory of the top of the central rotation axis; $W3$ is the space posture of the dynamic motion trajectory of the steel teeth; $W4$ is the space posture of the static motion trajectory of the steel teeth; W5 is the static motion trajectory of steel tooth tip.

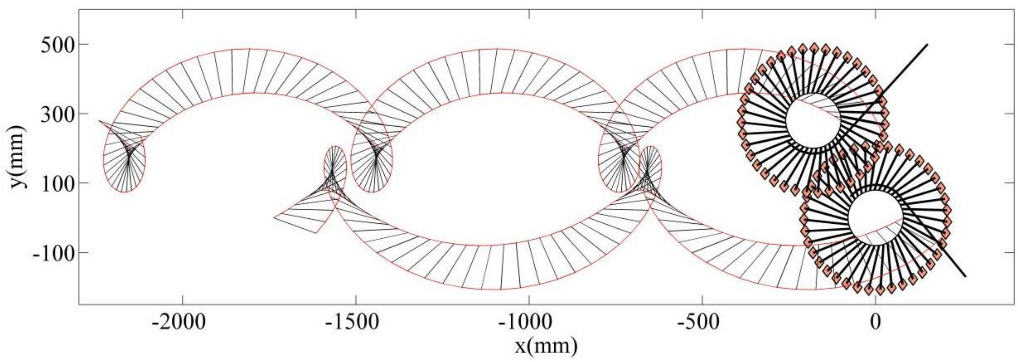

Fig. 5 - Simulation and optimization results of the double-roller picking and feeding mechanism
1. The protective plate of the picking roller; 2. The protective plate of the feeding roller

The dynamic and static motion trajectories of the double-roller picking and feeding mechanism are optimized. The operating posture of the rigid teeth in the picking and feeding roller mechanisms in operation is shown in Fig. 5. The combination of optimized parameters is shown in Table 2. When the inclination angle of the rigid teeth of the picking roller is -20°, it is beneficial for branch picking. At the same time, it forms an angle between it and the protective plate of the picking roller that is conducive to separating branches, reducing the loss of forced cutting of branches. Similarly, when the inclination angle of the rigid teeth of the feeding roller is -20°, the action of auxiliary feeding of branches can be completed. At the same time, the angle conducive to separating branches is formed between the protective plates of the feeding roller. When the rigid teeth are in a horizontal position, the branches basically complete separation under the action of the protective plate.

Table 2

Parameter optimization results of the double-roller picking and feeding mechanism

Parameters	Units	Picking roller	Feeding roller
Rotation center position	(x, y)	x= 0, y= 0	x= -180, y= 280
Radius of the rotation center position	(mm)	80	80
Length of the steel picking teeth	(mm)	130	130
Inclination of the steel picking teeth	(°)	-20	-20
Angle of the protective plate	(°)	-44	50
Rotation speed	(r/min)	33	42
Forward speed	(m/s)	0.5	0.5

Note: The inclination angle of the rigid picking teeth is the angle between the rigid teeth and the horizontal axis; The inclination angle of the rigid picking teeth is the angle between the deviation of the rigid picking from the center of the rotation axis to the root of the rigid teeth. The above direction is negative with clockwise inclination, and vice versa.

Test

Fig. 6 shows the performance test of picking in a rural and mechanical field in Shijiazhuang. First, the branches prepared in advance were weighed, and basically arranged according to the pruning amount of orchard branches of 5-7 years old. The weighed branches were then scattered on a 1.5 m wide and 10 m long channel. The laser tachometer was mounted on the side of the drive shaft to monitor the rotational speed. Finally, the time of passing through the position of the beginning and ending lines was recorded.

Fig. 7 shows that some branches are not treated and there is a phenomenon of "missing picking". Branches that have not been picked up are picked out of the crushed area to record. The method is as follows: the success rate of branch residue collection is defined as the percentage of the total weight of the successfully collected residues *(Xie et al., 2019)*. The picking success rate of branches *(Yu et al., 2018; Li et al., 2019; Popa et al., 2022)* is determined as follows:

Fig. 6 - Ground test of the picking roller

Fig. 7 - The missing branches

$$\eta_2 = \frac{W-W_r}{W} \times 100 \tag{13}$$

where η_2 is the picking success rate; W_r is the lost weight of branches, and W is the weight of the branches scattered on the ground during each test.

According to the data in Table 3, the success rate of picking is 91%. It can be seen that the collection data of this group meets the agricultural technical requirements of picking branches.

Table 3

Statistics of processing data of grapevine and pear branches by the crusher

Items	Branch length (branch)			Branch weight (g)		
	10~20(mm)	20~30(mm)	≥30(mm)	10~20(mm)	20~30(mm)	≥30(mm)
Branches	22	6	2	2678.4	316.2	189.3

CONCLUSIONS

(1) A theoretical model of the double-roller picking and feeding mechanism is established. Based on mathematical models, computer software is used to compile simulation programs. The static and dynamic picking and feeding trajectories of the execution part are simulated by human-machine window interaction. Computer simulation of the picking motion verifies the correctness of the theoretical model. According to the computer simulation, the spatial postures of the execution parts are presented to determine the main factors affecting the simulation motion, including the relative position of the picking roller and the feeding roller, roller speed, forward speed, inclination angle of rigid teeth and effective operating length. Univariate analysis is carried out on the main influencing factors to determine the optimization scope of individual factors. Finally, a set of non-inferior solution parameters are combined as follows: the picking roller, with a rotation center position of (0,0), a rotation center shaft radius of 80 mm, a rigid tooth length of 130 mm, an inclination angle of -20°, a protective plate angle of -44°, a rotation speed of 33 r/min, and a forward speed of 0.5 m/s; the feeding roller, with a rotation center position of (-180, 280), a rotation center shaft radius of 80 mm, a rigid tooth length of 130 mm, an inclination angle of -20°, a protective plate angle of 50°, a rotation speed of 42 r/min, and a forward speed of 0.5 m/s.

(2) The problems and causes of the double-roller picking and feeding mechanism during operation are analyzed as follows: the larger the inclination angle of the rigid teeth, the more the picking performance is enhanced. However, the separating process is not smooth, and even completely relies on the way of cutting the branches. When encountering large tree forks or large swallowing of branches, it is easy to cause stagnation and overload, which is not conducive to the smoothness of machine swallowing branches.

The results of the double-roller branch picking mechanism can provide data support for subsequent research on similar picking mechanisms, making the picking process be smoother. For example, it is applied to institutions for salvaging waste in wetland river basins.

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REFERENCES

1. Adamczyk, F., Dyjakon, A., Frackowiak, P., Romański, L. (2014). Conception of Machine for Pressing Branches with Pruning Fruit Tree. *Journal of Research and Applications in Agricultural Engineering*, Vol. 59(2), pp. 5-9. (in Poland)
2. Amirante R., Clodoveo M.L., Ruggiero, E.D.F., Tamburrano P. (2016). A tri-generation plant fueled with olive tree pruning residues in Apulia: An energetic and economic analysis. *Renewable Energy*, Vol. 89, pp. 411-421. https://doi.org/10.1016/j.renene.2015.11.085
3. Chen K., Yang X., Yan H., Guo Y., Wu J., Liu J. (2013). Design and Parameter Optimization of the Seedling Picking Mechanism of a Fully Automatic Transplanter Based on Matlab (基于 Matlab 的全自动移栽机取苗机构设计与参数优化). *Chinese Society of Agricultural Machinery*, Vol. 44, pp. 8-11. Doi: 10.6041/j.issn.1000-1298.2013.S1.005 (in Chinese)
4. Dyjakon A., Adamczyk F., Szaroleta M., Pari L., Suardi A., Germer S. (2018). Harvesting of agricultural wood residues from apple orchards using a pruning round baler. *Drewno*, Vol. 61(202), pp. 53-68. DOI:10.12841/wood.1644-3985.04.269.
5. Flick D.E., Nigon C.M., Shinners K.J., Friede J.C. (2019). Control system for a continuous compaction large square baler. *Computers and Electronics in Agriculture*, Vol. 165(June): 104969. https://doi.org/10.1016/j.compag.2019.104969.
6. Frąckowiak P., Adamczyk F., Wąchalski G., Szaroleta M., Dyjakon A., Pari L., Suardi A. (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*, Vol. 61(3), pp. 88-93.

7. Georges R., Auchet S., Méausoone P.J. (2014). A dynamic measurement of a disc chipper cutting forces. *Biomass and Bioenergy*, Vol. 64, pp: 269-275. https://doi.org/10.1016/j.biombioe.2014.02.033
8. He L., Fu, H., Karkee M., Zhang, Q. (2017). Effect of fruit location on apple detachment with mechanical shaking. *Biosystems Engineering*, Vol. 157, pp. 63-71. http://dx.doi.org/10.1016/j.biosystemseng.2017.02.009.
9. Lei J., Wang D., Li D., Zhang Q., Yang X., Na M. (2015). Analysis and Optimization of Factors Influencing the Formation of Rotating Grass Core in Steel Roller Round Bundling Machine (钢辊式圆捆机旋转草芯形成影响因素分析与优化). *Chinese Society of Agricultural Machinery*, Vol. 46(12), pp. 18-25. DOI:10.6041/j.issn.1000-1298.2015.12.003. (in Chinese)
10. Lei S., Ding L., Li J., Aiken Y. (2022). Study on Bending and Compression Characteristics of Pruning Branches of Jujube (枣树修剪枝条弯曲及压缩特性研究). *Journal of Agricultural Mechanization Research*, Vol. (5), pp. 198-203. DOI: 10.13427/j.cnki.njyi.2022.05.036 (in Chinese)
11. Li H., Yang A.Q., Li J.P. (2019). Subsection Curve Fitting Parameter of Spring-finger Cylinder on Branch Pickup Mechanism Calculated by Reverse Method (多段曲线拟合弹齿式枝条捡拾参数反求法求). *Journal of Agricultural Mechanization Research,* Vol. 41, 34-39. DOI: 10.13427/j.cnki.njyi.2019.09.006 (in Chinese)
12. Liao Q., Liu M., Zhang Z., Hu X. (2015). Multi-objective Optimization Design of Double Five-bar Transplanting Mechanism for Rape Pot Seedling (油菜钵苗移栽机双五杆栽植机构多目标优化设计). *Transactions of the Chinese Society of Agricultural Machinery*, Vol. 46(11), pp. 49-56. (in Chinese)
13. Mao P., Li J., Zhang S., Xu R. (2013). Kinematic Analysis of Seven-rod Planting Mechanism of Seedling Transplanter - Based on MATLAB (七杆式移栽机栽植机构运动学分析——基于 MATLAB). *Journal of Agricultural Mechanization Research,* Vol.12, pp. 59-62. DOI: 10.13427/j.cnki.njyi.2013.12.030 (in Chinese)
14. Mou X. (2015). Design of a Tracked Potato Harvesting and Plastic Film Recycling Compound Machine (履带式马铃薯收获与地膜回收复合作业机的设计), *Shandong Agriculture University*, 2015. (in Chinese)
15. Nona K.D., Lenaerts B., Kayacan E., Saeys W. (2014). Bulk compression characteristics of straw and hay. *Biosystems Engineering,* Vol. 118(1), pp.194-202. https://doi.org/10.1016/j.biosystemseng.2013.12.005
16. Popa L., Trokhaniak V., Constantin, A.M. (2022). Experimental research regarding the realization of an equipment intended for chopping woody waste. *INMATEH Agricultural Engineering*, Vol. 68(3), pp.757-766. https://doi.org/10.35633/inmateh-68-75
17. Velázquez-Martí B., Fernández-González E. (2009). Analysis of the process of biomass harvesting with collecting-chippers fed by pick up headers in plantations of olive trees. *Biosystems Engineering*, Vol. 104(2), pp. 184-190. https://doi.org/10.1016/j.biosystemseng.2009.06.017
18. Xie W., Li X., Fang Z., Quan Wei, Luo H., Wu M. (2019). Design of compound machine for rice straw collecting and continuous baling (水稻秸秆收集与连续打捆复式作业机设计). *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 35(11), pp. 19-25. (in Chinese)
19. Yu Z., Huai S., Wang W. (2018). Optimization of Omission Rate and Working Parameters of Roller Grass Picking Based on the Trajectory of Spring Teeth (基于弹齿轨迹的滚筒式牧草捡拾器遗漏率及工作参数优化).*Transactions of the Chinese Society of Agricultural Engineering*, Vol. 34, pp. 37-43. DOI:10.11975/j.issn.1002-6819.2018.04.005.
20. Yuan Z., Feng B., Zhao A., Liang A. (2002). Dynamic Analysis and Comprehensive Evaluation of Crop-Stem Lodging Resistance (作物茎秆抗倒伏的力学分析及综合评价探讨). *Transactions of the Chinese Society of Agricultural Engineering*, Vol. 18(6), PP. 30-31. (in Chinese)
21. Zeng Z., Chen Y. (2019). Simulation of straw movement by discrete element modelling of straw-sweep-soil interaction. *Biosystems Engineering*, Vol. 180, pp. 25-35. https://doi.org/10.1016/j.biosystemseng.2019.01.009