RESEARCH ON KINEMATICS SIMULATION AND DYNAMIC ANALYSIS OF THE COLLECTION MECHANISM OF ORCHARD BRANCHES
/
果园枝条收集机构的运动学仿真与动力学分析研究

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ABSTRACT
The spring finger collection mechanism is a core component of balers. It is usually used to collect soft straw crops (corn straw, wheat straw, green forage), and rarely used for hard stem crops (such as branch pruning residues). Due to different biophysical characteristics of hard stem crops and soft straw crops, the collection mechanisms are also different. In China, branch pruning residues in apple orchards are collected manually. It is a heavy labor task. To this end, this article uses an improved spring finger mechanism to collect pruning residues in apple orchard branches, effectively replacing manual collection operations. A dynamic motion trajectory simulation platform is developed by analyzing each action using pitchforks or other agricultural tools throughout the entire collection process, and combined with the structure of the spring finger collection mechanism. The platform of the spring finger collection mechanism is improved to collect orchard branches, and redesign and manufacture the core components of the collection mechanism. In addition, comparative tests were performed on4 different placement orientation sunder the conditions of R=40±2 r/min and V=0.9-1.1 m/s. That is, 1) messy, 2) transverse, 3) portrait orientation (the treetop firstly contacts the collection device), and 4) portrait orientation (the thick stems of the branches first touch the collection device). The results indicate that 1) and 2) have similar success rates in picking branches, while 3) and 4) have lower success rates, especially with 4) being the lowest). The analysis found that some branches were directly inserted into the spring finger gap and moved under the machine, resulting in a large amount of losses. This study aims to improve the success rate of picking branches in the bundling machine and verify the relationship between different placement directions and the success rate of picking branches.

摘要
弹簧指型收集机构是打捆机的核心部件，通常用于收集软秸秆作物（玉米秸秆、小麦秸秆、绿色牧草），而很少用于硬秸秆作物（树枝修剪残留物）。由于硬秸秆作物和软秸秆作物的生物物理特性不同，两者的收集机制也有所不同。在中国，苹果园的树枝修剪残留物是人工收集的。这是一项繁重的劳动任务。本文采用一种改进的弹簧指式机构收集苹果园枝条修剪残余物，以有效代替人工收集作业。通过分析在整个收集过程中使用干草叉或其它农具的每个动作，并结合弹簧指型收集机构本身的结构，开发了一个动态运动轨迹仿真平台。该平台对弹簧指型收集机构进行了改进以适应收集果园枝条，并对收集机构的核心部件进行了重新设计和制造。此外，在 R=40±2 R/min 和 V=0.9~1.1 m/s 的条件下，对 4 种不同的摆放位置进行了对比试验，即 1）杂乱、2）横向、3）纵向（树梢首先接触收集装置）和 4）纵向（树枝的粗茎首先接触收集装置）。结果表明，1）和 2）拾取树枝的成功率相似，而 3）和 4）的成功率较低，尤其是 4 最低），分析原因发现一些树枝直接插入弹簧指间隙并移动到机器下方，从而导致大量损失。本研究的目的是提高打捆机的拾取枝条成功率，并验证不同放置方向对拾取成功率的影响关系。

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INTRODUCTION

In recent years, the development and utilization of renewable energy has received more and more attention *(Romański et al., 2014).* In Poland, statistic results show that 60% of orchard farms are planted on an area greater than 5 hectares, and up to 71% are covered by apple orchards *(Adamczyk et al., 2014). A* large number of apple branch pruning residues are produced annually. *Spinelli and Picchi, (2010),* confirmed that the potential supply of wood from orchards ranged from 0.6 to 20 million m^3/year. For many years, most growers have treated the apple branch pruning residues by either stacking them together and burning them, or directly smashing them by a shredder to cover the soil *(Popa et al., 2022)*. Obviously, these methods do not bring economic benefits to growers and may pollute air quality and the environment.

In the last few years, some growers proposed to collect the scattered branch pruning residues from apple orchards using the collection mechanism of a baler, and then store the apple branch residues in baled form to replace wood as a fuel energy source *(Arkadiusz, 2019; Adamczyk et al., 2014)*. They conducted a feasibility assessment of using apple tree pruning residues in bales for energetic purposes, and suggested that the annual harvest of pruned biomass could be considered a good energy source for local heating systems *(Arkadiusz, 2018)*.

Ntalos and Grigoriou (2002) also stated that vineyard pruning residues could partly replace the traditional wood assortments for energy and industrial use. These pruning residues play an important subsidiary role in supplying bio-energy plants with renewable fuel *(Bernetti et al., 2006)*. Clearly, pruning residues are an important renewable biomass energy source that could bring some economic benefits if they could be conveniently collected and stored from orchards *(Arkadiusz, 2019).*

Currently, New Holland Company has developed and tested a round branch baler, demonstrating the feasibility of using a baler to collect branch pruning residues.

Fŕckowiak et al. (2016) reported that the Poznan Institute of Agricultural Engineering Industry developed a new machine for compressing branch pruning residues in orchards into round bales, and modified and reinforced the picking system of the branch baler.

Raffaele et al., (2012) reported that a new mini-baler system was designed and tested to recover pruning residues from vineyards where conventional tractors could not be used. But all of these rarely mention the pickup system of the machine.

In China, the spring finger collection mechanism is usually used to collect soft straw crops, and rarely for hard stem crops (such as apples, vineyards and olives). Since these branch pruning residues have biophysical properties with high wood fiber content, a relatively harder surface, less elasticity and resistance to deformation, they are different from soft straw crops. Therefore, the collection mechanism of soft straw crops is not suitable for hard stem crops.

Fu (2015) performed the structure design of the spring finger collection mechanism for collecting green forage and corn straws.

Xu et al., (2016), optimized the primary parameters of the spring finger collection mechanism for the two-stage harvest peanut straws. However, all reports have rarely investigated the spring finger collection mechanism used to collect hard stem crops.

The main objective of this study is to develop a hard stem crop collection mechanism for balers, considering picking height, picking angle, picking dynamic motion trajectory, picking speed and dynamic analysis. The purpose is to enhance the picking performance of the collection mechanism for hard stem crops, and to verify the optimal orientations of branches laid on the ground, so as to achieve better collection results.

MATERIALS AND METHODS

Process for collecting branch residues using farm implements

In a survey, in dwarfed and high-density planted apple orchards, most apple branches will be pruned and a new cycle of young branches will be created within 3-4 years to replace the old branches. *Zhen, (2017),* reported that the branches less than 35mm in diameter account for more than 90% of the pruning residues, and most of branch pruning residues end up close to the ground (Fig 1).

Some workers use a rake to pile branches and leave them in a swath on the ground. It is found that the rod of the rake forms a series of angles with the ground during collection. When these branch residues move next to the rake, the angle of the rake rod changes, and the angle changes in the range of 40°-70°. Other workers use a large pitchfork to lift the branch residues off the ground. Through the branch lifting process, the first insert angle into the piled branches is about 25°- 40°, and then the branches are lifted until the rod of the tool is horizontal to the ground.

The next step is to transport the branch residues to the entrance of the vehicle or shredder. Due to the high position of the entrance to the vehicle or the shredder, people stand on the side of the vehicle and the branches are lifted, and then the pitchfork moves in an arc to the entrance of the vehicle in the space. Finally, the pitchfork quickly breaks off from a set of branch residues to start a new cycle.

Fig. 1 - Distribution of branch pruning residues in an apple orchard

Kinetic analysis of the spring finger collection mechanism

To improve the branch picking performance of the baler, the spring finger collection mechanism is improved. The collection mechanism is a core component of the baler, which determines the percentage of retrieved branches relative to the total amount, directly influencing the baler collection performance. According to investigators who have demonstrated the use of agricultural tools to collect branches, the changes in the use of agricultural tools mainly involves angles, postures, and trajectories. Based on various crop straw collection devices, a spring finger collection mechanism is selected.

There are two reasons, that is, the trajectory and attitude are the key factors of the picking process, and the cam disk is the core component of the spring finger collection mechanism, which directly determines the trajectory and angle of the spring finger. The shape of the cam disk is improved to meet the collection requirements. The methods of separating branches preserve their integrity and allow them to be stored in bales.

Wang, (2012), reported the working principle of the spring finger cylinder collection device, which is mainly composed of spring fingers_ (1), crank_(2), link_(3), central axis_(4), cam disk_(5) and guard plate_(6), as shown in Fig. 2.

According to the angle of the spring finger in space, the entire cycle of the collection is divided into about five phases (gathering, lifting, transporting, feeding, separating and recovering). When using farm machinery, each stage of the collection mechanism will be matched with an operation. During the collection process of branches, Fig. 2 shows the force of branches. Force F is divided into F_1 (force in the horizontal direction) and F_2 (force in the vertical direction). α_1, α_2, α_3, $\alpha_4$and α_5 are the rotation angles of the central axis in the gathering, lifting, transporting, feeding, separating and recovering phases, respectively.

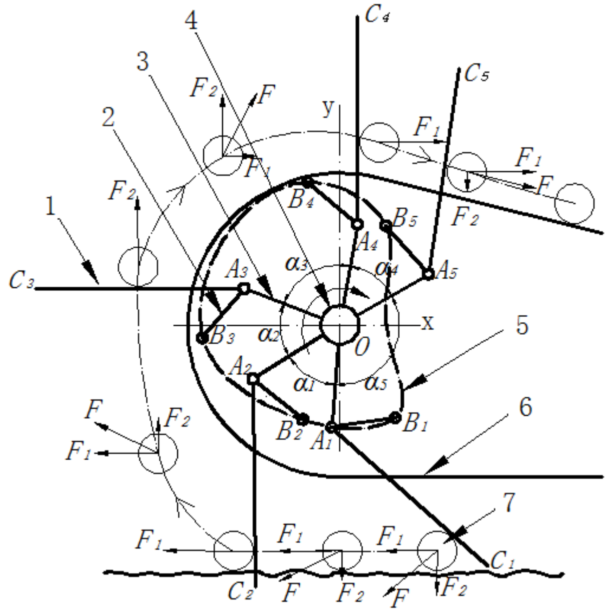


Fig. 2 - Kinetic analysis of the spring finger collection mechanism

The collection device mainly consists of spring fingers_ (1), crank_(2), link_(3), central axis_(4), cam disk_(5) and guard plate_(6), branch pruning residues_ (7). $\Delta A_1B_1C_1$, $\Delta A_2B_2C_2$, $\Delta A_3B_3C_3$, $\Delta A_4B_4C_4$ and $\Delta A_5B_5C_5$ are the collection mechanisms for different positions.

In Fig. 2, during the gathering phase_ (A_1C_1-A_2C_2), the spring fingers start to contact the branches and push them ahead, and then pile them together. F_1 has a critical influence on the branches laid on the ground during this phase. During the lifting phase_ (A_2C_2-A_3C_3), F_2 will increase gradually, and it will play a key role in taking branches off the ground. During the transporting phase_ (A_3C_3-A_4C_4), F_1 will change its direction compared with the above phases, and help the branches to move into the cavity of the baler. During the feeding phase_ (A_4C_4-A_5C_5), F will force the branches to follow the top side of the guard plate and slide into the cavity of the baler. During the separating and recovering phase_ (A_5C_5-A_1C_1), it will complete the separation between the spring finger and branches, and then recovery the original state. The data analysis and process are shown in Table 1.

Table 1

Kinetic analysis in each phase of periodic collection

Each phase of collection	Stress on branches		α	β		The moving position of the spring finger in space
	F_1	F_2		Start	End	
Gathering	-↑	-↓	α_1	The far end of the spring finger touches the ground	90°	A_1C_1-A_2C_2
Lifting	-↓	+↑	α_2	90°	180°	A_2C_2-A_3C_3
Transporting	+↑	+↓	α_3	180°	270°	A_3C_3-A_4C_4
Feeding	+↓	-↑	α_4	270°	Vertical between the spring finger and the top side of the guard plate	A_4C_4-A_5C_5
Separating and recovering	0	0	α_5	The spring finger withdraws to the inner of the guard plate	The far end of the spring finger contacts the ground	A_5C_5-A_1C_1

Note that the collection mechanism rotates clockwise as the positive direction. α is the rotation angle of the middle center axis; β is the angle between the spring finger and the horizontal coordinate axis in the coordinate system; '↑' is the gradual increase; '↓' is the gradual decrease. '+' is the positive direction in the coordinate system, and '-' is the negative direction in the coordinate system.

Optimization objectives

In the collection cycle, point *O* acts as the rotation center of the coordinate systemin Fig. 2. The collection mechanism rotates clockwise.

(1) During the gathering phase, if the angle of the spring finger is over-inclined, the effective length of the spring finger would be affected, resulting in the reduced storage space, which may lead to "congestion" or "overload" phenomena. The spring finger should thus remain at an angle of 45°-55° in contact with the branches laid on the ground.

(2) To obtain the lower picking height of the collection mechanism (the shortest distance between A_3C_3 and the ground in Fig. 2), the spring finger should contact the branches as early as possible, and the angle(α_1) of the gathering phase should be reduced to meet the demand.

(3) According to the kinetic analysis of the lifting phase, F_1 has an adverse influence on the branches. The angle_(α_2) of the lifting phase being reduced as soon as possible to prevent the branches from flying out after collision with the spring finger. The optimal solution is to lower the picking height of the collection mechanism to keep the collection system stable.

(4) During the transporting and feeding phases, the spring finger changes its angle as soon as possible and the angle_(α_3) of the central axis is reduced as much as possible to reach the vertical angle sooner. This generates a stronger pull force on the branches, and then the spring finger will form a favorable angle to strengthen the feeding performance of the collection mechanism.

(5) During the feeding phase, the rotation angle_(α_4) of the central axis is increased as much as possible to prolong the feeding distance. The vertical angle of the spring finger is positioned to meet the tensile force needs of the branch group.

(6) During the separation and recovery phase, the spring finger will gradually retract along the vertical direction at the top of the guard plate to avoid clamping the branches and not being able to separate. The angle of the spring finger should be recovered to the original state as soon as possible in the rotation angle_(α_5) of this phase.

Dynamic simulation of the collection mechanism

A mathematical model is first established based on the structure of the collection mechanism. Then the static and dynamic simulation programs are compiled in MATLAB to optimize these primary parameters of the mathematical model, through the interaction of human-computer *(Wuet al., 2008).* The dynamic simulation (Fig. 5) displays the actual running trajectory and the angle of the collection mechanism. Combined with experts' experience, the optimal angle and trajectory for branch collection are selected. The effective collection distance indicates the running distance of the spring finger on the operation plane.

The effective rate of the collection distance (η_1) is determined using the equation:

$$\eta_1 = \frac{K_2K_1}{K_3K_2 + K_2K_1} \times 100 \tag{1}$$

Where:

η_1 is the effective rate (%) of the collection distance within an entire cycle;

K_2K_1 is the collection distance in the dynamic movement trajectory;

K_3K_2 is the distance of the loss collection in the dynamic movement trajectory.

Prototype open verification

To implement the testing task smoothly, a rectangular baler with a spring finger collection mechanism was selected as the experimental carrier. The focus is on redesigning the picking-up mechanism.

In Table 2, the critical data on the collection mechanism were measured and the optimization process was performed. The center-line data value of the cam disk groove was obtained. *Li et al., (2019)* reported the method of processing the data of the cam disk groove with MATLAB. In accordance with these final data, the shape of the cam disk (Fig. 3) was redesigned, and some relative components (Fig. 4) were improved. The collection system was tested with these improved components. In addition, because the other components of the collection mechanism are unchanged, these original parts no longer require modification.

Fig. 3 - Cam disk

Fig. 4 - Some improved relative components

This experiment was conducted in an open square at an agricultural company located in Shijia Zhuang, China. First, the branch residue was laid on a 15m long and 1.8m wide lane, and then 4 different branch residue orientations, messy, transverse and longitudinal (the treetops first contact the collection device, and the thick stems of the branches contact the collection device first) were set. In addition, a laser tachometer was used to measure the rotation speed and the scales were used to measure the total weight of branch residues before testing and the loss weight of branch residues after testing (Table 2).

Table 2

Prepared tests and parametric condition measurements

Branch pruning residue orientations laid on the ground			**Test equipment parameters**
Messy branches			Tractor: Dongfanghong-MF604 Scales: Edberg NK/HP (within 5kg) G&G/Shuangjie SW-6234C (5~30 kg) Laser Tachometer: SW-6234C Fig.2, the length of the spring finger_ (1) =120 mm, the length of the crank_ (2) =45 mm, the radius of link_ (3) + the radius of central axis _ (4) =67 mm, ∠B1A1C1=39°.
Transverse orientation			
Portrait orientation	The treetop first contacts the collection device		
	The thick stems of branches first contact the collection device		

Note that the forward direction of the tractor is in portrait, and the vertical is transverse.

The success rate of branch residue collection is defined as the percentage of the successfully collected branch residues against the total weight.

The success rate of the picking system for branch residues is determined by using equation (2):

$$\eta_2 = \frac{W - W_r}{W} \times 100 \tag{2}$$

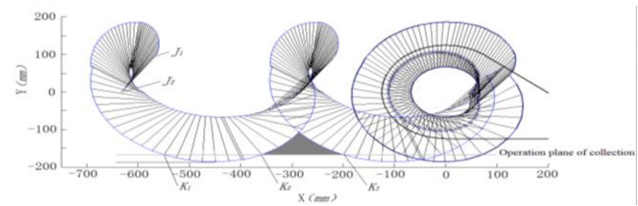
where, η_2 is the success rate (%) of picking; W_r is the loss weight of branch residues, and W is the weight of the total branch residues scattered on the ground in each test.

RESULTS AND DISCUSSION

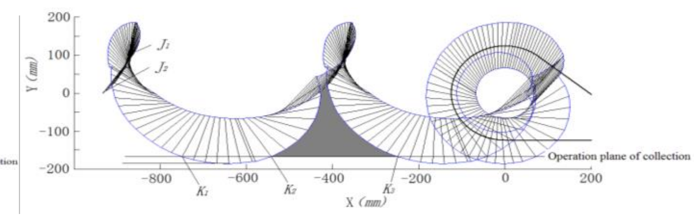
Dynamic simulation results for the collection mechanism

In Fig. 5, as the tractor moves forward, one of the spring fingers in the collection mechanism is simulated. The dynamic movement trajectory of the collection mechanism clearly shows the position and angle of the spring finger during these two running periods. Suppose the tip of the spring finger is inserted into the soil 10 mm deep to ensure that it touches the branches on the ground. As such, a line is set in the dynamic motion trajectory as the acquisition operation plane.

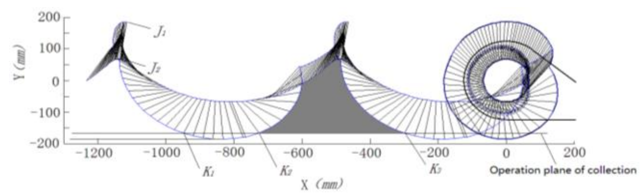
As shown in Fig. 5, when V increases, the ring of the top of the trajectory reduces gradually or even vanishes. The gray area is the loss collection area, gradually expanding, which will obviously be detrimental to collection.



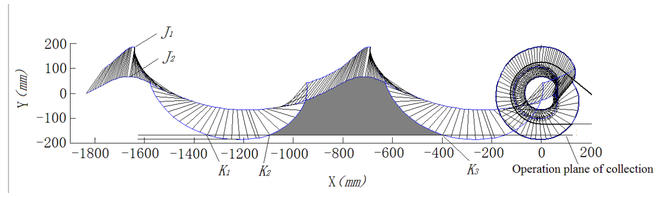
(a) *R*=55 r/min, *V*=350 mm/s



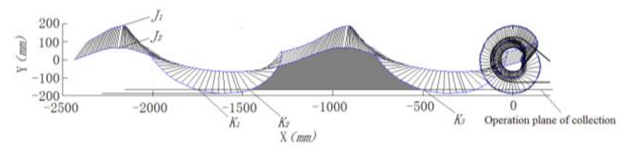
(b) *R*=55 r/min, *V*=500 mm/s



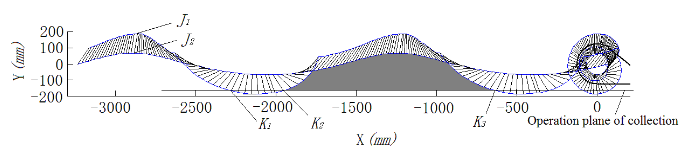
(c) *R*=55 r/min, *V*=650 mm/s



(d) *R*=55 r/min, *V*=950 mm/s



(e) *R*=55 r/min, *V*=1250 mm/s



(f) *R*=55 r/min, *V*=1650 mm/s

Fig. 5- The dynamic simulation trajectory of the collection mechanism at R=55 r/min and different forward speeds

R is the rotation speed of the collection mechanism; V is the velocity of the tractor; K_1 is the end point of effective collection in the operational plane; K_2 is the start point of effective collection in the operational plane, and the end point of loss collection in the operational plane. K_3 is the start point for loss collection in the operational plane; K_3K_2 is the distance of the loss collection; K_2K_1 is the distance of effective collection; J_1J_2 is the spring finger angle *which shows the minimum angle for feeding the dynamic movement trajectory.*

Note that the minimum feeding angle in the dynamic movement trajectory is an angle between J_1J_2 and the horizon plane.

Table 3

Parameterdata in the dynamic movement trajectory

R r/min	***V*** mm/s	**Coordinate**			***K₃K₂*** (mm)	***K₂K₁*** (mm)	***η₁*** (%)	**Coordinate**		**Minimum feeding angle**	**Ring trajectory**	
		K₃	***K₂***	***K₁***				***J₁***	***J₂***		**Point *C₁***	**Point *A₁***
55	350	(-199.3, -167)	(-358, -167)	(-549.3, -167)	158.7	191.3	54.7	(-564.2, 98.3)	(-633,0)	49.01°	Y	Y
	500	(-248.7, -167)	(-542.1, -167)	(-748.7, -167)	293.4	206.6	41.3	(-864.2, 98.3)	(-933,0)	47.99°	Y	N
	650	(-298, -167)	(-726.3, -167)	(-948, -167)	428.3	221.7	34.11	(-1115, 185.2)	(-1135, 67)	80.4°	Y	N
	950	(396.8, -167)	(-1095, -167)	(-1347, -167)	698.2	252	26.53	(-1639, 185.2)	(-1659, 67)	80.4°	N	N
	1250	(-495.5, -167)	(-1463, -167)	(-1745, -167)	967.5	282	22.56	(-2163, 185.2)	(-2184, 67)	79.92°	N	N
	1650	(-627.1, -167)	(-1954, -167)	(-2277, -167)	1326.9	323	19.58	(-2861, 185.2)	(-2882, 67)	79.92°	N	N

Note that 'Y' is the existing ring trajectory and 'N' indicates that it does not exist. Point C1 and A1 are shown in Fig. 2.

The data in Table 3 show that when V increases, the distances of the collection (K_2K_1) and the loss collection (K_3K_2) both enlarge, and the occupying rate (η_1) of the former decreases gradually in the collection cycle. The tractor running speed is too fast under the same rotation speed, which is not conductive to the collection operation. Due to the increase in speed, the top ring trajectory gradually disappears, and the minimum feed angle of the spring finger also changes. When the entire top ring trajectory disappears completely, the minimum feed angle of the spring finger within the dynamic motion trajectory remains unchanged.

Comparing the changes of the minimum feed angle, the results show that when there is a ring trajectory, the minimum feed angle value is greatly reduced relative to the ring trajectory when it disappears.

According to the kinetic analysis of the feeding phase in Table 1, the angle of the spring finger in the range of 40°- 60° will be conducive to the feed action. The minimum feeding angle meets the feeding requirement. The analysis results in Table 3 and Fig. 5 of the ring trajectory will directly affect the feeding of collection. As V increases, the ring trajectory appears, and the collection ability is weakened gradually. When V reaches a certain value, the spring teeth will not provide an effective feeding.

Open validation testing

Comparing 4 different orientations of branch residue collections in Table 4, it is found that Fig. 6 (a) and Fig.6 (b) have similar picking success rates at almost the same tractor velocity and rotation speed of the collection mechanism. Through the collection video_ Fig. 6 (b), it is clear that the spring finger begin to push the branches forward in the lateral direction, and then stack together similar to the messy orientation.

The video of Fig. 6 (c) shows that the branches easily move to two sides of the collection mechanism, resulting in the loss of some branches. The branch orientation of Fig. 6 (d) makes the picking difficult, because the thick stems of some branches are inserted directly into the gap between the spring fingers, which loses its hold on the branches. After the thick branches are sent below the collection mechanism, most of the branches will not be collected. Thereby the orientation in Fig. 6 (d) should be avoided as much as possible when the branch residues are laid on the ground.

The picking data in Table 4 can guide people to arrange the branch residues as close as possible to the orientations of Fig. 6 (a) or Fig. 6 (b), and then the branches can be stacked together, but the height of the piles should be limited.

(a) The messy orientation of branches

(b) The transverse orientation of branches

(c) The treetop orientations first contact the collection device

(d) The thick stems of the branches first contact the collection device

Fig. 6 - The influence of different orientations of branches on the success rate of picking

Table 4

The success rate of picking branches at different orientations

Laid orientations	*V* (m/s)	*R* (r/min)	Weight (kg)		η_2 (%)
			W	*Wr*	
Fig. 6a)	0.9−1.1	40±2	15±0.2	0.84	94.4
Fig. 6b)				1.30	91.3
Fig. 6c)				4.72	68.5
Fig. 6d)				9.22	38.5

CONCLUSIONS

In this study, the collection process of branch residues was simulated on a dynamic basis, with a kinetic analysis for each motion of the entire collection cycle. The angle of the spring finger and the trajectory of the end of the spring finger were determined through the human-computer interaction interface in an entire collection cycle. The core components of the collection mechanism were redesigned, fabricated and tested, and the site evaluation tests were carried out on 4 different orientations of branch residues laid on the ground, from which the following conclusions can be drawn:

(1) The improved spring finger collection mechanism can achieve a satisfactory picking success rate of branch pruning residues, which proves the availability and potential of this method.

(2) The messy and transverse orientations facilitate the collection of branch pruning residues.

(3) The portrait orientation for branches should be avoided, especially when the thick stems of the branches first touch the spring finger. They easily move in the direction of the collection mechanism axis through the gap between the spring fingers, resulting in loss.

Further, different parameters of the spring finger collection mechanism will be studied and different phenomena will be recorded to provide basic data for other researchers and solve the compatibility problem with a baler. In addition, the device is also suitable for the removal of surface wastes.

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REFERENCES

[1] Adamczyk, F., Dyjakon, A., Frąckowiak, P., Romański, L. (2014). Conception of machine for pressing branches with pruning tree fruit. *Journal of Research and Applications in Agricultural Engineering,* Vol. 59, 5-9. Poland.

[2] Arkadiusz, D. (2018). Harvesting and Baling of Pruned Biomass in Apple Orchards for Energy Production. *Energies,* Vol. 11, 1680. Basel, Switzerland.

[3] Arkadiusz, D. (2019). The Influence of Apple Orchard Management on Energy Performance and Pruned Biomass Harvesting for Energetic Applications. *Energies,* Vol. 12, 632. Basel, Switzerland.

[4] Bernetti, I., Fagarazzi, C., Fratini, R. (2006). A methodology to analyze the potential development of biomass energy sector: an application in Tuscany. *Forest Policy and Economics*, Vol. 6, 415-32. United States.

[5] 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, 88-93. Poland.

[6] Fu, W. J. (2015). *Design and Field Experimental Study of pick up roller on corn straw collecting grinder (玉米秸秆捡拾粉碎机设计及田间性能试验研究)*. Xinjiang Agricultural University. China.

[7] 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解). *Journal of Agricultural Mechanization Research,* Vol. 41, 34-39. Heilongjiang/China.

[8] Ntalos, G. A., Grigoriou, A. H. (2002). Characterisation and utilisation of vine prunings as a wood substitute for particle board production. *Ind Crop Prod,* Vol.16, 59-68. Netherlands.

[9] 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, Issue 3, pp.757-766. https://doi.org/10.35633/inmateh-68-75

[10] Raffaele, S., Carla, N., Luigi, P., Enzo, M., Natascia, M. (2012). Production and quality of biomass fuels from mechanized collection and processing of vineyard pruning residues. *Applied Energy,* Vol.89, 374-379. England.

[11] Repullo, M. A., Carbonell, R., Hidalgo, J., Rodríguez-Lizana, A., Ordóñez R. (2012). Using olive pruning residues to cover soil and improve fertility. *Soil and Tillage Research*, Vol.124, 36-46. Netherlands.

[12] Romański, L., Dyjakon, A., Adamczyk, F., Frąckowiak, P. (2014). Problems With Deriving the Fruit Tree Pruned Biomass for Energy Use. *Agricultural Engineering,* Vol. 3, 157-167. Poland

[13] Spinelli, R., Picchi, G. (2010). Industrial harvesting of olive tree pruning residue for energy biomass. *Bioresource Technology,* Vol.101, 730-735. Netherlands.

[14] Wang, W. (2012). *Parameter analysis and improving design of spring finger cylinder pick up collector (弹齿滚筒式捡拾装置参数分析和改进设计研究).* Inner Mongolia Agricultural University. 19~21. China.

[15] Wu, C. Y., Zhao, Y., and Chen, J. N. (2008). Optimization design of transplanting mechanism of rice transplanter based on visualization human-computer interaction (水稻插秧机分插机构人机交互可视化优化设计). *Transaction of the Chinese Society for Agricultural Machinery.* Vol.39, 46-49. Beijing/China.

[16] Xu, T., Shen, Y. Z., Gao, L. X. (2016). Spring-finger Peanut Pickup Mechanism Based on Two-stage Harvest (基于两段收获的弹齿式花生捡拾机构研究). *Transactions of the Chinese Society for Agricultural Machinery,* Vol.47,90-97. Beijing/China.

[17] Zhen, J. X. (2017). *Research on Fruit Tree Branch Processing Machine Based on Field Return Technology (基于就地还田技术的果树枝条处理机的研究)*. Hebei Agriculture University. China