

Article

Design on the Winter Jujubes Harvesting and Sorting Device

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Abstract: According to the existing problems of winter jujube harvesting, such as the intensive labor of manual picking, damage to the surface of winter jujubes, a winter jujube harvesting and sorting device was developed. This device consisted of vibration mechanism, collection mechanism, and sorting mechanism. The eccentric vibration mechanism made the winter jujubes fall, and the umbrella collecting mechanism can collect winter jujube and avoid the impact of winter jujube on the ground, and the sorting mechanism removed jujube leaves and divided the jujube into two types, and the automatic leveling mechanism made the device run smoothly in the field. Through finite element analysis and BP (Back Propagation) neural network analysis, the results show that: The vibration displacement of jujube tree is related to the trunk diameter and vibration position; the impact force of winter jujubes falling is related to the elastic modulus of umbrella material; the collecting area can be increased four times for each additional step of the collection mechanism; jujube leaves can be effectively removed when blower wind speed reaches 45.64 m/s. According to the evaluation standard grades of the jujubes harvesting and sorting, the device has good effects and the excellent rate up to 90%, which has good practicability and economy.

Keywords: winter jujube; harvesting and sorting; vibration mechanism; automatic leveling

1. Introduction

Winter jujube (*Ziziphus jujuba* Mill. cv. Dongzao) is a famous Chinese fruit. People like its flavor, crispness and succulence, and it is rich in nutrients [1]. The planting area of winter jujubes in China has exceeded 2×10^7 m³, which reflects its popularity. The harvesting process of winter jujubes is a very important step, characterized by strong seasonality and labor intensity [2], and the labor used accounts for 35% to 45% of the labor used in the entire production process. The traditional way of picking winter jujubes is to knock the fruit trees manually, and then sort and bag the fallen winter jujubes on the ground [3,4]. This way costs a lot of manpower and material resources, and it is easy to cause damage to the jujubes. Therefore, how to achieve the safe picking and automatic classification of winter jujubes has become a key research issue.

At present, some scholars have conducted a lot of researches on the harvesting methods of granular fruit, and put forward such methods as vibration picking and suction picking [5–7]. These methods reduce the labor intensity of fruit farmers to some extent. Jun Peng et al. carried out in-depth research on the simulation analysis of the vibration picking of winter jujubes, and established the simulation framework of the vibration response of jujube trees under the vibration excitation, and used the finite

element method to find the relationship between the response and the excitation frequency. However, the effect of tree size and shape on the amplitude of jujube tree was not considered [8]. The study of the instantaneous response and movement state of the fruit during the different stages of fruit shedding was carried out by the experimental data of and a two-pendulum kinetic model was established to provide theoretical basis for analyzing the fruit vibration shedding characteristics, optimizing the design parameters of the vibration harvester and improving the fruit recovery rate [9]. Du xiaoqiang et al. designed a small-sized fruit collection device with lateral folding and spreading, whose overall structure is inverted umbrella with two ends supported and fan-shaped, to expand the collection area, which solved the problem of large volume, complex structure, and high requirements on fruit tree row spacing [10]. Qin Guangjiuet al. have developed a kind of automatic sorting equipment for winter jujube. By combining photoelectric separation and mechanical separation, they have successfully separated the winter jujube of different sizes and different maturity [11].

In view of the above problems, this paper puts forward a design scheme of the winter jujube harvesting and sorting device. The winter jujubes fall by vibration, then the leaves and jujubes are separated, and achieve automatic classification of the size of the jujubes finally. A discriminant analysis of BP neural network based on MATLAB was carried out to verify the rationality of the design.

2. Overall Working Principles

As is shown in Figure 1, the winter jujube harvesting and sorting device was composed of vibration mechanism, collection mechanism, sorting mechanism, and automatic leveling mechanism.

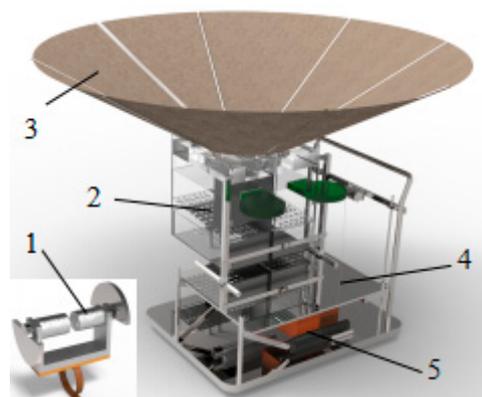


Figure 1. Structure diagram of winter jujube harvesting and sorting device: (1) Vibration mechanism; (2) sorting mechanism; (3) collection mechanism; (4) automatic leveling mechanism; (5) control core.

The specific working principle of the device is as follows: The vibration mechanism is fixed on the jujube tree, and a rubber pad is used to isolate the contact area with the trunk, so as to reduce the damage of the tree in the vibration process. The DC motor drives two eccentric blocks to rotate in opposite directions, thus driving the jujube tree to vibrate, while the jujubes fall under the action of inertial force. The excitation force generated by the eccentric block is related to the rotating speed of the motor. In order to facilitate the adjustment of the motor speed, a blue-tooth remote control device is designed. The rotating speed is adjusted remotely through the handheld terminal, which is easy to operate and can guarantee the safety of fruit farmers. The collection mechanism is composed of eight uniformly distributed skeletons and nonwoven fabrics with certain elasticity. The winter jujubes roll along the inclined umbrella towards the center under the action of gravity. The sorting mechanism consists of two symmetrical sorting boxes, which can rotate with each other to surround the jujube tree in the middle. The side of the sorting box is equipped with a blower, which can blow the jujube leaves into the sorting mechanism out of the box. In the process of transportation, the level detection sensor detects the level of the device in real time and feeds back to the putter motor for adjustment to ensure the smooth operation of the device.

3. Key Components Design

3.1. Vibration Mechanism

3.1.1. Dynamic Model of Vibration Harvesting

At present, there are three main methods for picking winter jujubes: Hand picking, suction picking, and vibration picking. Among them, hand picking requires human beating of fruits with high labor intensity and low efficiency, and it is easy to cause damage to the jujubes. The suction picking needs complicated equipment, and the technology is not yet mature. The vibration picking device is simple, easy to operate, and the acquisition rate of fruit is high. Therefore, a small eccentric vibration picking mechanism of winter jujubes was designed as shown in Figure 2, and it consists of eccentric blocks [12], direct current motor (DC motor), fixation bracket, etc.

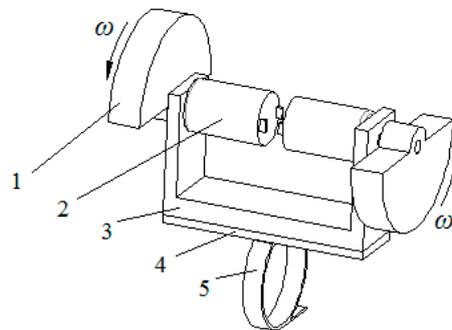


Figure 2. Vibration mechanism diagram: (1) Eccentric block; (2) direct current motor; (3) fixation bracket; (4) rubber pad; (5) fixed belt.

The forced vibration of jujube tree under external harmonic excitation can be simplified to a second-order linear mass-spring system. The motion differential equation of this system can be obtained by Equation (1) [13].

$$m\ddot{x} + c\dot{x} + kx = F(t) = F_0 \sin(\omega t) \tag{1}$$

where, m is the mass of the vibration system, kg; k is the stiffness coefficient, N/m; c is the damping factor, N·s/m; x is the vibration displacement, mm; F is the exciting force, N; F_0 is the maximum exciting force, N; t is the time, s; ω is the frequency, Hz.

All the solutions of the differential equation x include a general solution x_1 and a particular solution x_2 , and $x = x_1 + x_2$. In the case of small damping, the general solution x_1 is not considered, and the special solution is set as:

$$x_2 = X \sin(\omega t - \varphi) \tag{2}$$

where, X is the amplitude of forced vibration, mm; φ is the phase angle, rad.

Equation (2) was substituted into Equation (1), and we can get,

$$(k - m\omega^2)X \sin(\omega t - \varphi) + c\omega X \cos(\omega t - \varphi) = F_0 \sin(\omega t) \tag{3}$$

Rewrite $F_0 \sin(\omega t)$ at the right end of the above expression as,

$$F_0 \sin(\omega t) = F_0 \sin[(\omega t - \varphi) + \varphi] = F_0 \cos \varphi \sin(\omega t - \varphi) + F_0 \sin \varphi \cos(\omega t - \varphi) \tag{4}$$

Substitute Equation (4) into Equation (3), and the equation can be obtained:

$$[(k - m\omega^2)X - F_0 \cos \varphi] \sin(\omega t - \varphi) + (c\omega X - F_0 \sin \varphi) \cos(\omega t - \varphi) = 0 \tag{5}$$

This equation is equal to 0 for any time t , therefore,

$$(k - m\omega^2)X - F_0 \cos \varphi = 0 \tag{6}$$

$$c\omega X - F_0 \sin \varphi = 0 \tag{7}$$

Thus,

$$X = \frac{F_0}{\sqrt{(k - m\omega^2)^2 + (c\omega)^2}} \tag{8}$$

$$\tan \varphi = \frac{c\omega}{k - m\omega^2} \tag{9}$$

Equations (8) and (9) divide the numerator and denominator by k , and we can get:

$$X = \frac{F_0/k}{\sqrt{[k - (\frac{\omega}{\omega_n})^2]^2 + [2\zeta(\frac{\omega}{\omega_n})]^2}} \tag{10}$$

$$\tan \varphi = \frac{2\zeta(\frac{\omega}{\omega_n})}{1 - (\frac{\omega}{\omega_n})^2} \tag{11}$$

where, $\omega_n = \sqrt{\frac{k}{m}}$, $\zeta = \frac{c}{c_c}$, $c_c = 2m\omega_n$. The ω/ω_n is called frequency ratio. The main function of the conversion here is to simplify the formula form and make it more tidy.

From the above analysis, the specific solution of the equation can be written:

$$x_2 = \frac{F_0/k}{\sqrt{[k - (\frac{\omega}{\omega_n})^2]^2 + [2\zeta(\frac{\omega}{\omega_n})]^2}} \sin(\omega t - \varphi) \tag{12}$$

In this mechanism, two eccentric blocks with identical shape and size are installed on both sides of the support symmetrically. Under the same angular velocity, the excitation force changes in sin form, and the direction of the force is perpendicular to the connection of the rotating center of two eccentric blocks.

$$F(t) = F_0 \sin(\omega t) = 2m_e R \omega^2 \sin(\omega t) \tag{13}$$

where, m_e is the mass of eccentric block, kg; R is the eccentricity of the eccentric block, m, $R = \frac{4r}{3\pi}$; ω is the angular velocity of the eccentric block, rad/s; $\omega = \frac{\pi n}{60}$, where n is the motor speed, rev/min.

For the stiffness coefficient k , it is assumed that acting on a radial thrust P of the trunk of the jujube tree, the deflection of the applied point of force is:

$$\delta_s = \frac{Pl^3}{3EI} \tag{14}$$

where, l is the distance between the operating point in and the ground, m; E is the elastic modulus, GPa; I is the moment of inertia, m^4 .

The cross section of the trunk of the jujube is approximately circular with a diameter of D , then,

$$I = \frac{\pi D^4}{32} \tag{15}$$

At this time, the force required for the unit static deformation of jujube tree trunk is the stiffness coefficient,

$$k = \frac{P}{\delta_s} = \frac{3EI}{l^3} = \frac{3\pi ED^4}{32l^3} \tag{16}$$

It can be seen that the vibration displacement of jujube is related to the diameter and vibration position of the trunk.

3.1.2. Finite Element Modeling Analysis of Jujube Trees

The typical high-quality production of jujube trees after pruning and shaping are free spindles, natural open heart, stratified evacuation, and natural round head. Among them, the free spindle-shaped frame is firm, the shaping is simple, the yield is easy, the management is convenient, is suitable for close planting and cultivation, therefore the free spindle-shaped shaping method has been widely used in the jujube tree planting process. After shaping, tree height is 2.8–3.3 m, 5–8 a central dry evenly on the center stem, spread outward in 70–80° angle, and the distance between the adjacent two main branches is 30 cm.

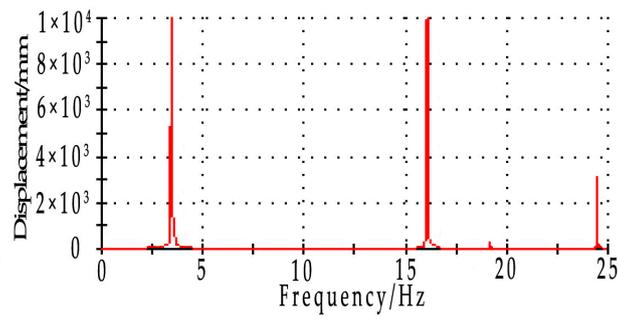
In this experiment, the free spindle-shaped jujube tree was selected for SolidWorks 3D modeling [14], and simplify the jujube tree model. In general, the higher the height of the jujube tree, the greater the displacement caused by the same vibration. The height of the normal winter jujube tree is about 2.8–3.2 m, and the typical height we selected during the modeling process is 3 m, and center of the lower trunk is cylindrical. The main branch above 1.5° in the draft, five main branches are evenly distributed on top of it. Each main branch is stretched outward at a distance of 30 cm at an angle of 75°, and its length and diameter are equally distributed. When performing finite element analysis, the elastic modulus of the jujube is 10 GPa. Due to the high-water content of the living tree, the material density is 1000 kg/m³, regardless of the external force, the damping coefficient is taken as 0 [15,16].

First, consider the influence of trunk diameter D on vibration displacement, respectively, take $D = 150$, $D = 175$, $D = 200$, $D = 225$, $D = 250$ mm, and make a modal analysis of jujube tree model. The DC motor used in this paper is continuously adjustable under the remote control of the Bluetooth module, and the vibration speed can be continuously adjusted within 0–1500 r/min. Therefore, the vibration mechanism can provide the vibration frequency of 0–25 Hz. In this frequency range, the natural frequency of jujube vibration of different diameters is shown in Table 1.

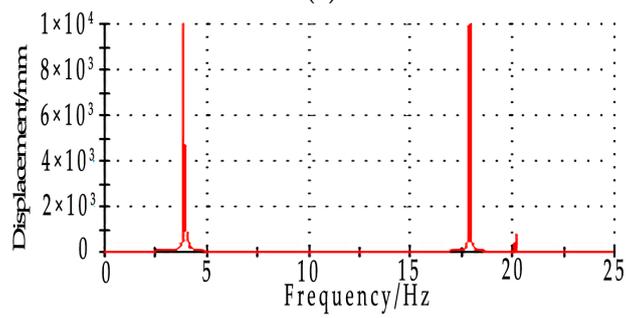
Table 1. Natural frequency table of jujube trees with different diameters.

Order	Natural Frequency/Hz				
	$D = 150$ mm	$D = 175$ mm	$D = 200$ mm	$D = 225$ mm	$D = 250$ mm
1	3.4804	3.8818	4.6748	5.477	6.2831
2	3.5338	3.9212	4.7147	5.5163	6.3217
3	12.495	15.006	17.107	18.752	19.987
4	16.107	17.918	20.70	21.36	21.851
5	16.911	18.501	21.116	24.066	
6	19.19	20.139	21.508	24.324	
7	23.201	24.52			
8	24.483				

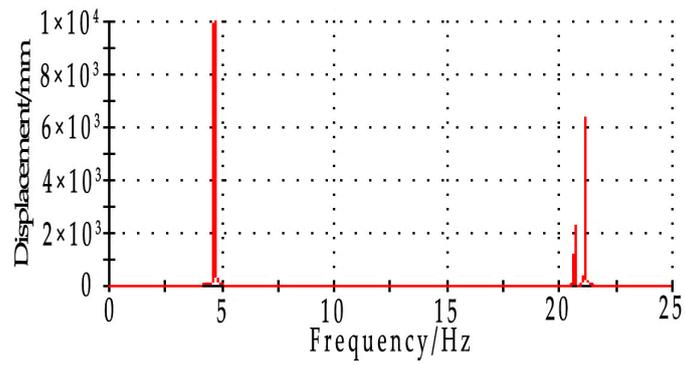
Resonance is a phenomenon in which the amplitude of the system increases significantly when the excitation frequency of the system is close to the natural frequency of the system. However, when the excitation frequency and the natural frequency are close, resonance does not always occur [17,18]. Therefore, it is necessary to further explore the excitation frequency that causes the jujube to resonate according to the natural frequency. If the test of each mode is a complicated and cumbersome work, this paper adopts the harmonic analysis of the jujube tree model to find the resonance point within the required range at one time. Any complex wave can be composed of many sinusoidal components with different frequencies, amplitudes and phases, and the harmonic analysis is to decompose them. In the trunk of the jujube tree 1 m away from the ground, the exciting force is applied, and all suitable frequencies are swept one by one. The obtained harmonic analysis diagram is shown in Figure 3.



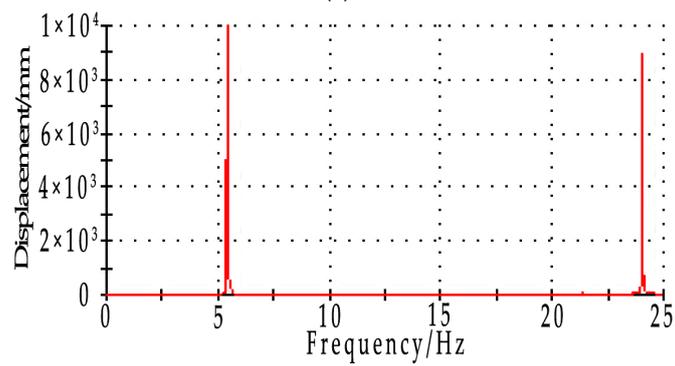
(a)



(b)



(c)



(d)

Figure 3. Cont.

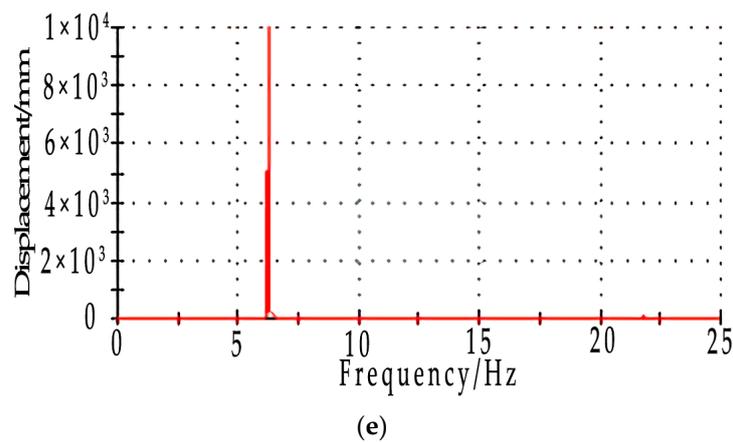


Figure 3. Harmonic analysis diagram: (a) $D = 150$; (b) $D = 175$; (c) $D = 200$; (d) $D = 225$; (e) $D = 250$ mm.

It can be seen from Figure 3 that not all-natural frequencies will cause the jujube to resonate. For example, when $D = 150$ mm, the natural frequency of jujube tree has eight orders in the range of 25 Hz, but the resonance only occurs under the first order, the fourth order, and the eighth order. Therefore, through harmonic analysis we can quickly find all the resonance frequencies. In order to further clarify the relationship between the vibration displacement of the jujube tree and the diameter of the trunk, the influence of the rotational speed on the exciting force is not considered in the finite element simulation process, and the maximum exciting force that can be generated by the vibration mechanism is unified. In the vibration mechanism designed in this paper, the eccentric block is fan-shaped, with a central angle of 180° , a radius of $r = 200$ mm, a thickness of $d = 100$ mm. The material used is ISO C45 steel, which is a kind of carbon steel with the carbon content about 0.45%, and its density is 7.85 g/cm^3 . The maximum exciting force generated by the eccentric block can be obtained by Equation (17).

$$F_0 = 2M_E R \omega^2 = \frac{\pi}{45} \rho r^3 d n = 657.13 \text{ N} \quad (17)$$

After performing harmonic analysis, we found all the resonance points of different forms of jujube trees. One order vibrational form of each type of jujube tree was selected for analysis, and the selected vibration orders are respectively the fourth order (0.062 s), the fifth order (0.054 s), the first order (0.214 s), the first order (0.183 s), and the first order (0.159 s). The natural frequency period is applied with a load of 657.13 N, and the linear dynamics simulation is performed. The resulting displacement cloud is shown in Figure 4. The center stem and the main branch end point are extracted separately, and the relationship between the displacement of the corresponding point and time is detected, and the displacement map of each node with time is obtained. The result is shown in Figure 5. In the process of continuous vibration, the main function of damping is to reduce the amplitude of the resonance and make the frequency response curve become smoother, thus the effect of damping on the resonance frequency is small. On the other hand, in order to simplify the calculation process of the simulation and save the calculation time, the effect of damping on the resonance frequency was ignored. It can be seen that the displacement of each point on different diameter jujube trees increases with time. When the vibration time is the same, the vibration displacement of the same position on different jujube trees decreases when the diameter of the trunk increases.

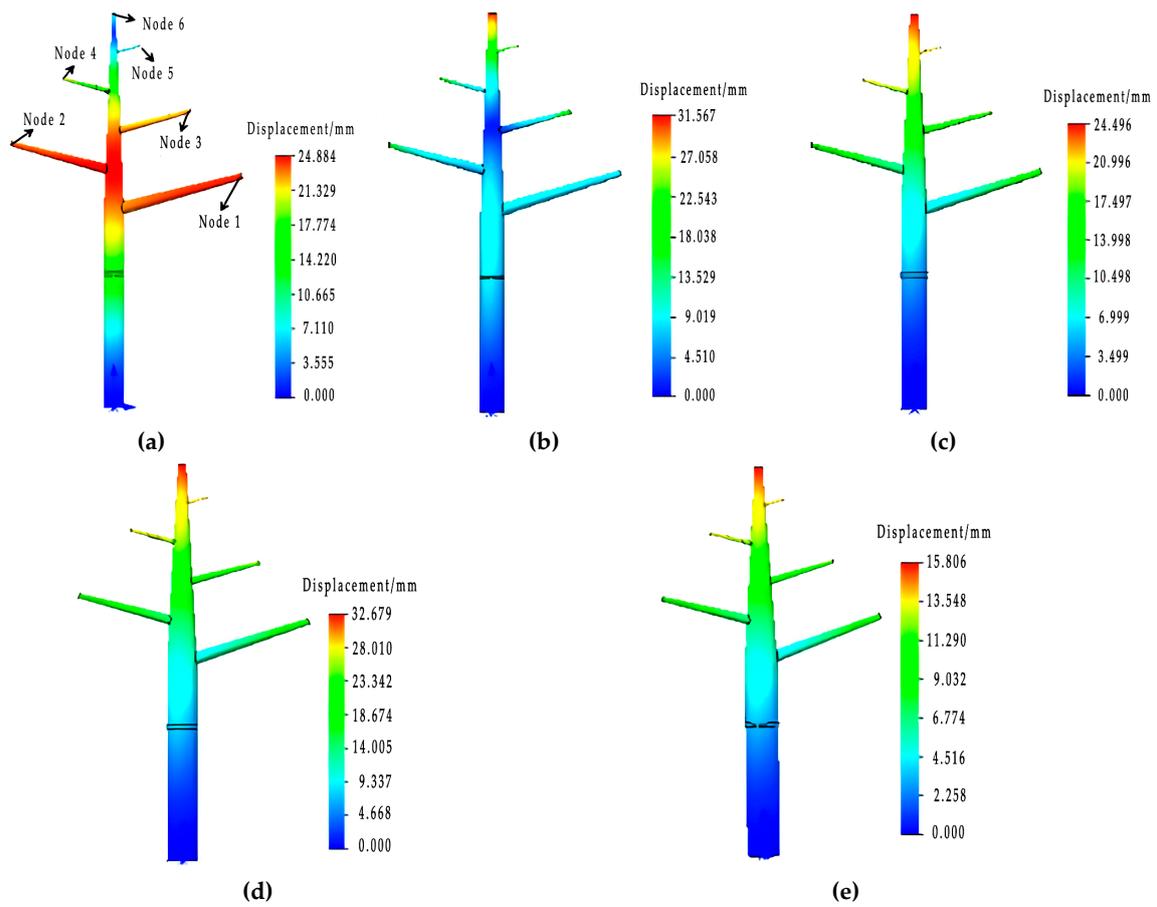


Figure 4. Resonance displacement cloud map of jujube trees with different diameters: (a) $D = 150$ mm, the fourth order, 16.107 Hz; (b) $D = 175$ mm, the fifth order, 18.501 Hz; (c) $D = 200$ mm, the first order, 4.6748 Hz; (d) $D = 225$ mm, the first order, 5.477 Hz; (e) $D = 250$ mm, the first order, 6.2831 Hz.

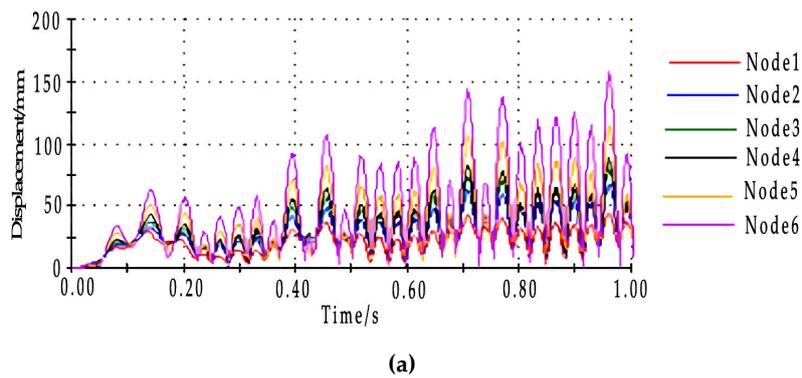


Figure 5. Cont.

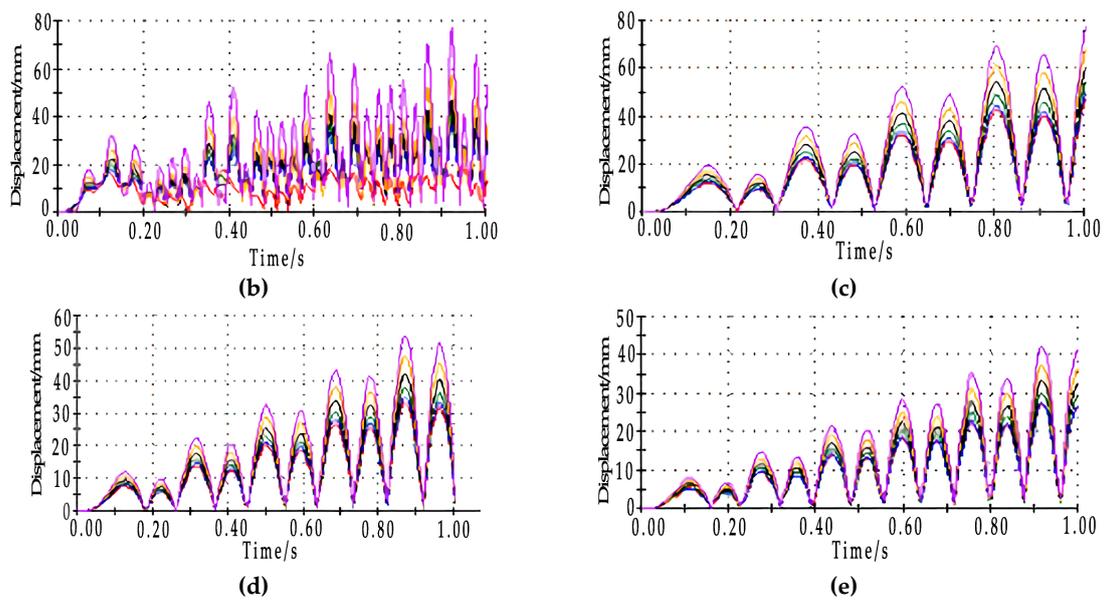


Figure 5. Resonance displacement cloud map of jujube trees with different diameters: (a) $D = 150$ mm, four order, 16.107 Hz; (b) $D = 175$ mm, five order, 18.501 Hz; (c) $D = 200$ mm, one order, 4.6748 Hz; (d) $D = 225$ mm, one order, 5.477 Hz; (e) $D = 250$ mm, one order, 6.2831 Hz.

Secondly, consider the influence of the vibration point (the vertical distance l of the fixed position of the vibration mechanism and the ground) on the vibration displacement of the jujube tree, take the diameter $D = 150$ mm, respectively at $l = 500, l = 750, l = 1000, l = 1250, l = 1500$ mm. The excitation force was applied, and the dynamics simulation was performed in the fourth-order mode. The experimental cloud image is shown in Figure 6.

Different from the above-mentioned simulation of the influence of the diameter on the vibration displacement of jujube trees, the jujube trees have the same size and shape, and the external excitation is the same. The displacement of the end points of the jujube trees at the same time (0.05 s) is detected, as shown in Figure 7. It can be seen that under the same external excitation, the position of the vibration mechanism fixed on the center stem is farther from the ground, and the vibration displacement generated by each node of the jujube tree is larger.

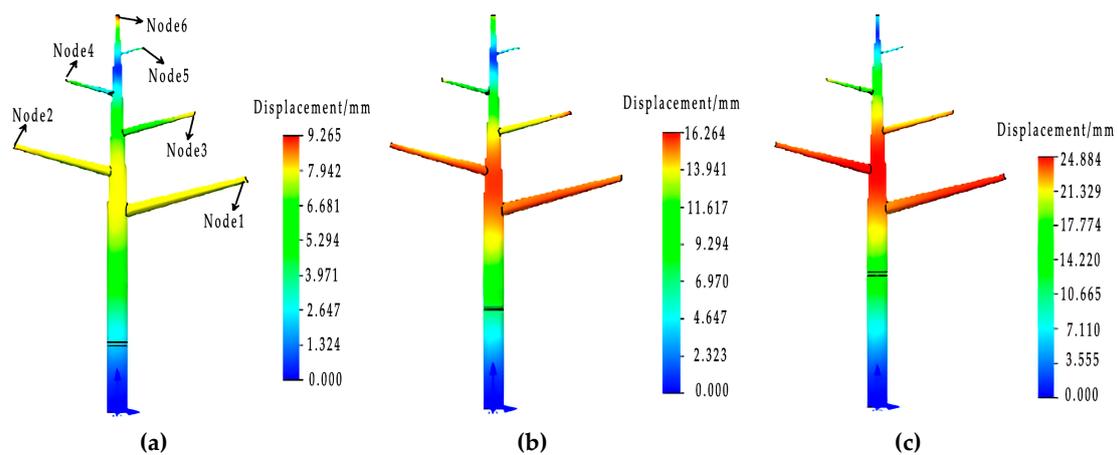


Figure 6. Cont.

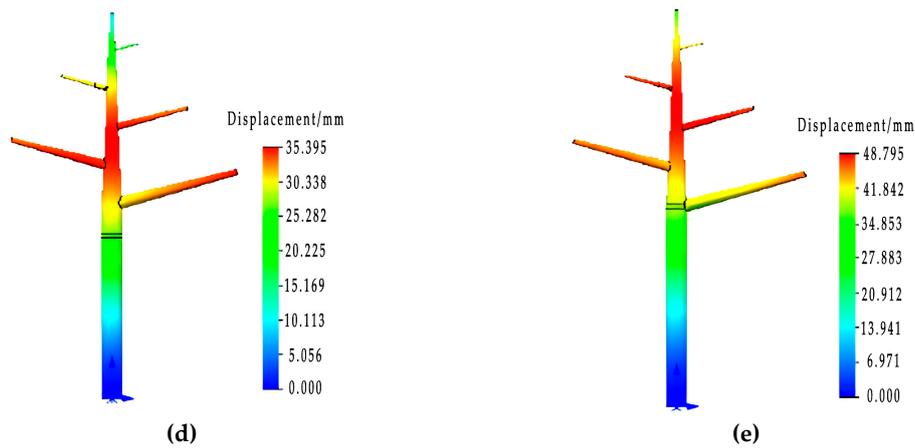


Figure 6. The vibration displacement cloud map of jujube tree at different vibration points: (a) $l = 500$ mm, the fourth order, 16.107 Hz; (b) $l = 750$ mm, the fourth order, 16.107 Hz; (c) $l = 1000$ mm, the fourth order, 16.107 Hz; (d) $l = 1250$ mm, the fourth order, 16.107 Hz; (e) $l = 1500$ mm, the fourth order, 16.107 Hz.

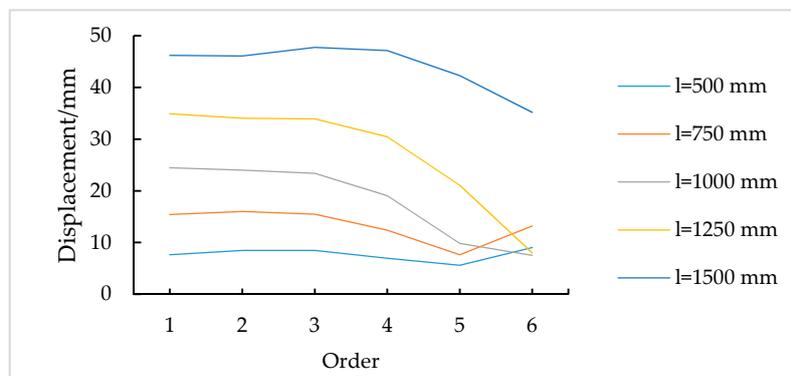


Figure 7. The maximum displacement of each node of jujube tree at the same time.

3.2. Collection Mechanism

The winter jujube is easily damaged by collision because it contains more water, and the fruit meat is more brittle. When the jujube falls, if it falls on the ground directly, it will cause surface injury. The quality and storage time of the winter jujubes will decrease. Currently, the traditional solution for farmers is that they put plastic cloth around the jujube trees to prevent the jujubes from landing on the ground directly. Although this method has a certain buffering effect, there are still some flaws. First, the plastic cloth is directly in contact with the ground. When the ground is dry and hard, the buffering effect will be greatly reduced. Second, when the jujubes fall onto the plastic cloth, they cannot be collected in time, and the later fallen jujubes may hit the first dropped jujubes, causing double damage [19]. In response to such problems, a variable area umbrella-like collecting mechanism as shown in Figure 8 was designed.

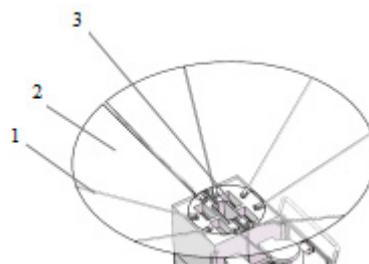


Figure 8. Folding umbrella collection mechanism: (1) Skeleton; (2) nonwoven fabric; (3) falling entrance.

Ignoring the influence of air resistance, the jujubes are free falling in the process of falling. According to the law of conservation of energy, the speed of the jujubes when they contact the ground is:

$$v = \sqrt{2gH} \tag{18}$$

where, v is the speed when the jujube hits the ground, m/s; g is the acceleration of gravity, m/s²; H is the distance between the jujube and the ground, m.

Then, combining the theorem of momentum $m_p v = Ft_c$, the average impact force when the jujube hits the ground can be obtained by Equation (19).

$$F = \frac{m_p \sqrt{2gH}}{t_c} \tag{19}$$

where, F is the average impact force, N; m_p is the mass of winter jujube, kg; t_c is contact time, s.

It can be seen that the average impact force is inversely proportional to the contact time. Compared with the falling on the ground directly, the contact time of falling on the nonwoven fabrics with a certain elasticity is increased greatly, and the impact force on the jujube can be reduced effectively [20].

Due to the different canopy sizes of jujube trees, the umbrella with fixed area cannot meet the demands for use. Therefore, this paper designed a composite folding umbrella bone, as shown in Figure 9. When the tree canopy is large, it can be connected with the second rod on the first rod. One end of the connecting rod is connected with the second rod by rotation, and the other end is connected with the sliding block by rotation. The sliding block can be moved along the first rod and the limit block is used to define the limit position of the movement. Each rod is connected by a rotation spindle and pin, which can be disassembled easily, and the fruit farmers can carry out multistage combination in accordance with the actual situation. In the design process, the length of each rod is L , then the collection area of the first rod can be obtained by Equation (20).

$$S_1 = \pi r_g^2 = \pi L^2 \cos^2 \theta \tag{20}$$

where, S_1 is the collection area of the first rod, m²; L is the length of the rod, m; θ is the angle of the first rod and horizontal plane, (°).

When another rod group is increased, the corresponding collection area is as follows:

$$S_2 = \pi(L \cos \theta + L \cos \theta')^2 = \pi L^2 (\cos \theta + \cos \theta')^2 \tag{21}$$

where, S_2 is the collection area of the second rod, θ' is the angle of the second rod and horizontal plane, (°).

When the sliding block moves to the limit position, $\theta \approx \theta'$, then, $S_2 = 4S_1$. Thus, it can be seen that the collection area of the device can be increased by four times for each rod group being increased, which is suitable for the collection of jujube trees with a different size of canopy.

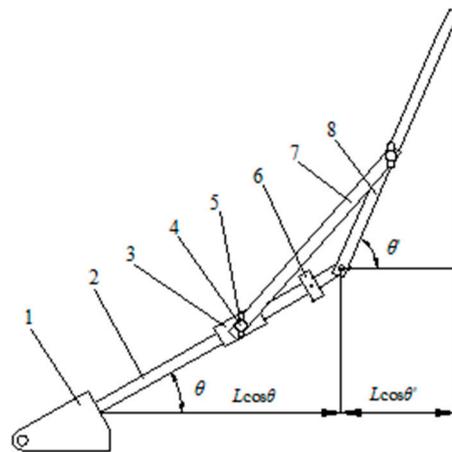


Figure 9. Umbrella skeleton design diagram: (1) Fixed block; (2) first rod; (3) sliding block; (4) rotation spindle; (5) pin; (6) limit block; (7) connecting rod; (8) second rod.

3.3. Sorting Mechanism

In the process of vibrating jujubes, some leaves will fall as well, which is not conducive to the collection of winter jujubes. Secondly, the size of the winter jujube has a great influence on its selling price, so fruit farmers will classify the winter jujubes by size and sell it in package. However, manual sorting is time-consuming and laborious [21]. In view of this problem, we designed an automatic sorting mechanism to realize the size classification of winter jujubes and the removal of leaves. The mechanism is shown in Figure 10. The sorting mechanism consists of two symmetrical sorting boxes, which can rotate with each other to surround the jujube tree in the middle. The side of the sorting box is equipped with a blower, which can blow the jujube leaves out of the box. Under the blower, there is a layer of soft network arranged in a strip. Due to the heavy mass of winter jujubes, they can continue to fall through the soft network, while the leaves that are not blown out of the box during the falling process are separated so that they cannot pass through the soft network for their light mass. There is a layer of screen plate under the soft network which is installed through slots for easy replacement, and the angle between it and the base plane is 20° . There are square holes with a fixed size on the screen plate, and small winter jujubes will fall into the small jujube storage box through square holes. The larger winter jujubes cannot pass through the square holes and roll into the large jujube storage box along the inclined screen plate under the action of gravity. When jujube is small enough but not aligned to the hole for sorting, it also slides on the screen plate, and drops from the hole below during the slide. The screen plates with different size square holes were designed for fruit famers to choose according to the actual size of the winter jujubes.

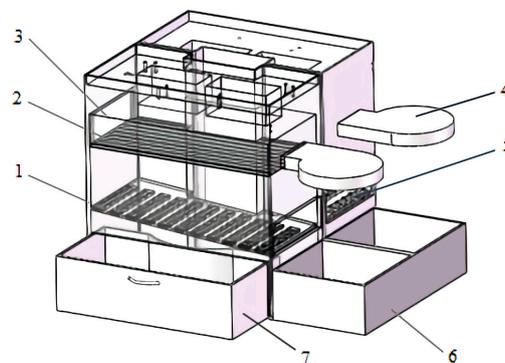


Figure 10. Sorting mechanism diagram: (1) Screen plate; (2) soft network; (3) jujube leaves export; (4) blower; (5) jujubes export; (6) the large jujube storage box; (7) the small jujube storage box.

In the process of blowing out jujube leaves, the wind speed of the blower has a great influence on the removal of leaves, and the mathematical modeling analysis is performed. The falling process of jujube leaves is affected by both gravity and blow force. The blow force can be obtained by Equation (22).

$$F_c = Q\Delta v = v^2s \tag{22}$$

where, F_c is the blow force, N; Q is flow, m^3/s ; Δv is the wind speed difference value, m/s ; v is the wind speed, m/s ; s is the leaf area, m^2 .

The jujube leaves are falling free in the vertical direction, and the drop time can be determined by the free fall formula:

$$h = \frac{1}{2}gt^2 \tag{23}$$

where, h is the vertical falling distance, m ; t is the falling motion time, s .

The jujube leaves are accelerated in the horizontal direction, and the motion distance can be obtained by Equation (24).

$$l = \frac{1}{2}a_c t^2 = \frac{1}{2} \frac{F_c}{m_l} \frac{2h}{g} = \frac{v^2sh}{m_lg} \tag{24}$$

where, m_l is the mass of jujube leaf, kg ; a_c is the transverse acceleration, m/s^2 .

In order to obtain the parameters used in the formulas, we measured the mass and area of 200 jujubes and leaves, respectively. Then, we recorded the measurement data and calculated the average value. Finally, winter jujube mass $m_l = 0.01$ kg , is the smallest and largest projected area of jujube leaves in vertical wind direction $S_{max} = 3 \times 10^{-4}$ m^2 , $S_{min} = 0.6 \times 10^{-4}$ m^2 . According to the above equation, the wind speed for blowing out jujube leaves can be obtained at 20.41–45.64 m/s .

3.4. Automatic Leveling Mechanism

The overall design of the device is in the form of a trolley. However, due to the bumpy ground in the orchard, as well as more weeds, branches and fallen leaves, the movement of the device is blocked and bumpy, which is easy to cause device damage and is not conducive to the transport of the winter jujubes. Therefore, the traditional trolley was modified and the automatic leveling mechanism as shown in Figure 11 was designed to increase the stability of the device during the movement [22].

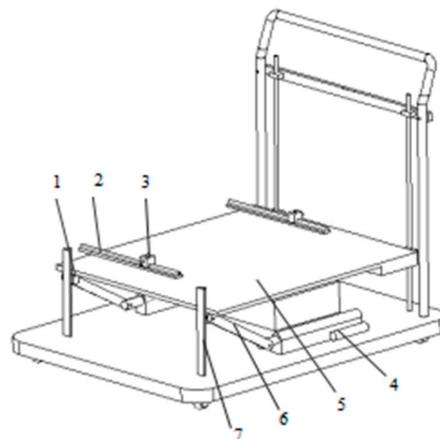


Figure 11. Automatic leveling mechanism diagram: (1) Top blocks; (2) sliding guide rails; (3) sliding blocks; (4) linear actuators; (5) carrying platform; (6) connecting rods; (7) guide rails.

Two linear actuators (the XTL100 type, produced by Longxiang Hardware Flagship Store, Jiangsu, China) are installed at the bottom of the device to push the top blocks up and down along the guide rails through the connecting rods, and further drive the side of the carrying platform. The other side of the platform is articulated with the rack, which can realize rotation. A horizontal detection sensor

(the CQ-100D type, produced by Qingdao Youtian Measurement & Control Technology Co., Ltd., Qingdao, China) is installed on the bottom surface of the platform to measure the levelness of the carrying platform, and the feedback is given to the control system to control the corresponding elongation and shortening of the linear actuators. When the front end of the trolley is hoisted, the linear actuator shrinks, and when the front end of the trolley drops, the linear actuator elongates. The carrying platform is always kept in the horizontal state to prevent the occurrence of capsizing events. The surface of the platform is equipped with sliding blocks and sliding guide rails. When the device is moving in the field, the sorting boxes move along the sliding guide rails track to the platform, and the trolley pushes forward. When picking, two sorting boxes slip to the side of the platform and surround the jujube tree.

4. Results and Discussion

4.1. Test Parameters

The physical prototype made by using the above design method is shown in Figure 12. In order to verify the rationality of the design, related field experiments were carried out. The experimental site was the Nantong Civic Forest Farm, China, and the picked winter jujube variety is Zhanhua Dongzao. The height of this variety of jujube trees is about 3 m, and the planting interval of jujube trees is about 5 m. The terrain in the field is relatively small; there are no weeds between the main roads, and there is no wind during the test. For comparison, two kinds of picking methods are adopted. The device designed in this paper is used for mechanized picking, and the second is manual picking. The manual picking is beating winter dates using bamboo poles, so that the jujubes fall. The main test parameters include acquisition rate, collection rate, damage rate, miscellaneous rate, and misclassification rate.



Figure 12. The prototype of winter jujube harvesting and sorting device.

The acquisition rate refers to the ratio between the number of fallen winter jujubes and the total number of winter jujubes to be harvested. After the vibration is over, the unexfoliated winter jujubes are knocked off the trees by the measure of human beating, and the corresponding number is recorded. The acquisition rate can be obtained by Equation (25).

$$P_r = 100 \frac{N_r}{N_r + N_u} \quad (25)$$

where, P_r is acquisition rate, %; N_r is the number of fallen winter jujubes by vibration; N_u is the number of fallen winter jujubes by artificial beating.

Due to the adjustable vibration frequency, the amplitude of jujube trees may be too large at some time, resulting that some of the winter jujubes fall outside the umbrella collection mechanism.

The collection rate refers to the ratio between the number of winter jujubes that fall into the boxes and the number of winter jujubes that fall in vibration, which can be obtained by Equation (26).

$$P_c = 100 \frac{N_c}{N_r} \quad (26)$$

where, P_c is the collection rate, %; N_c is the number of winter jujubes falling into the boxes.

Some winter jujubes may cause surface damage when they fall outside the collecting mechanism. The damage rate refers to the ratio between the number of winter jujubes with surface damage and the number of winter jujubes that fall in vibration, and it can be obtained by Equation (27).

$$P_d = 100 \frac{N_d}{N_r} \quad (27)$$

where, P_d is the damage rate, %. N_d is the number of winter jujubes with surface damage.

The miscellaneous rate refers to the ratio of the mass of jujube leaves in the jujube box to the mass of jujube and jujube leaves, which reflects the negative performance of the device, expressed in P_t :

$$P_t = 100 \frac{m_y}{m_y + m_z} \quad (28)$$

where, P_t is the miscellaneous rate, %; m_y is the mass of the jujube leaf in the jujube box, kg; m_z is the mass of the jujube in the jujube box, kg.

When classifying the winter jujubes, the large jujubes cannot be transferred into the small jujube storage box through the screening holes. However, due to excessive accumulation on the screening plate, the small jujubes cannot fall into the small jujube storage box in time. Instead, due to gravity, they roll into the large jujube storage box, resulting in classification error. The misclassification rate refers to the ratio of the number of mis-division jujubes to the total number of winter jujubes in the jujube box, expressed in P_i .

$$P_i = 100 \frac{N_m}{N_c} \quad (29)$$

where, P_i is the impurity content, %; N_m is the number of mis-divisions.

4.2. Test Method and Result Analysis

In order to comprehensively consider the above five test parameters to evaluate the harvesting and sorting effect of the device, this paper designs an evaluation model for the harvesting and sorting of winter jujube based on the MATLAB (MATLAB 7.10 R2010a 2010.3.5) neural network. In the experiment, several parameters of the device were tested to evaluate the performance of the device. This is a problem where multiple inputs produce a single output which can be solved by neural network. First, we generate multiple sets of data to train the neural network, and then migrate the trained model. Finally, we use the designed device for parameter testing. Then, enter the tested parameters into the model, and the model will automatically output an evaluation result. The evaluation results are divided into five levels, and Table 2 is the evaluation standard table for the collection and sorting of winter jujube. The values of each evaluation parameter are interval values. Using the `rand()` function in MATLAB, the values corresponding to the range are randomly generated, and a total of 5000 learning samples are generated. Then, use the `premnmx()` function to preprocess the learning samples, quantize the values of each parameter into the range $[-1,1]$, and then use each parameter value as the input unit, and the corresponding level as the expected output, thus establishing the evaluation model.

The author conducted a large number of experiments and randomly extracted 10 sets of experimental data from them. `premnmx()` function is used for preprocessing, and the target vectors of excellent to unqualified five levels are set to: $(1,0,0,0,0)^T$, $(0,1,0,0,0)^T$, $(0,0,1,0,0)^T$, $(0,0,0,1,0)^T$, $(0,0,0,0,1)^T$, and input to the designed BP network model. The `sim()` simulation function is called to realize the evaluation output of the harvesting and sorting condition of winter jujube. The specific network output results and evaluation grades are shown in Table 3.

The results show that the winter jujube harvesting and sorting device designed in this paper has a good effect, and the excellent rate can reach 90%, which meets the requirements of fruit farmers.

Table 2. Evaluation standards table.

Grade	Evaluation Parameters				
	$P_r/\%$	$P_c/\%$	$P_d/\%$	$P_t/\%$	$P_j/\%$
Excellent	>95	>95	<5	<1	<5
Good	90	90	7	2	10
Medium	85	85	9	3	15
Qualified	80	80	12	4	20
Unqualified	<70	<70	>15	>5	>25

Table 3. Output and evaluation level.

Serial Number	Excellent	Good	Medium	Qualified	Unqualified	Grade
1	0.9547	0.0014	0.0001	0.0002	0.0000	Excellent
2	0.0000	0.8867	0.0018	0.0002	0.0009	Good
3	0.0000	0.4847	0.9518	0.0005	0.0000	Medium
4	0.0013	0.9480	0.0010	0.0036	0.0001	Good
5	0.0109	0.8935	0.0007	0.0002	0.0662	Good
6	1.0503	0.2657	0.0002	0.0266	0.0000	Excellent
7	0.9945	0.0595	0.0000	0.0335	0.0000	Excellent
8	0.9872	0.0127	0.0000	0.0022	0.0006	Excellent
9	0.0012	0.9783	0.0092	0.0006	0.0002	Good
10	0.0000	0.9858	0.0000	0.0094	0.0000	Good

5. Conclusions

In this paper, we designed a winter jujube harvesting and sorting device, which can realize the functions of vibration picking, automatic sorting, leveling transportation, etc., and determine the key structures and operating parameters, such as eccentric block and blower, which can ensure the safe picking of winter jujube and realize size classification.

The eccentric vibration mechanism causes the winter jujube to fall. The vibration displacement of the jujube tree is related to the diameter of the jujube tree and the position of the vibration mechanism. Under normal circumstances, the smaller the diameter, the higher the vibration point, and the greater the vibration displacement of each point on the jujube tree. The umbrella collecting mechanism can avoid direct impact between the jujubes and the ground, and the rod group can be selected according to the actual size of the canopy of the jujube tree, and the collection area of the device can be increased by four times for each rod group being increased. The sorting mechanism can divide the fallen winter jujubes into two categories, and remove the leaves. According to the evaluation standard grades of the harvesting and sorting of winter jujubes, the superior rate can reach 90%, and the device works well and meets the demands of fruit farmers.

There are also some shortcomings in this article. For example, the modal analysis of jujube trees ignores the influence of the damping coefficient, which is somewhat different from the real situation. Secondly, when too many jujubes are dropped at the same time, the jujubes will be crowded on the screen plate, which will result in misclassification. These are the issues we need to solve in the future.

6. Patents

The authors of this paper have carried out research on the winter jujube harvesting and sorting device for many years. One China invention patent related to this paper has been published, the patent number is CN109808932A.

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