ISSN: 2688-8645

Design and Ansys Finite Element Analysis of a Shaking-type Winter Jujube Harvesting and Collection Device

Yang Li, Weihui Wang, Zuomin Wang, Hewei Lu, Jianjun Zhang

School of Mechanical and Automotive Engineering, Qingdao University of Technology, Qingdao 26600, China

Abstract

In order to effectively improve the efficiency of winter jujube picking and collection while ensuring a low damage rate, facilitating the quick collection of winter jujubes, a vibration-type lightweight winter jujube picking and collection device is proposed. It consists of a rope-stretched umbrella collection device, a retractable vibration-assisted picking claw, a toothed locking device, etc. Mainly driven by manpower to stretch the rope and rotate the umbrella rod with a torsion spring to expand the umbrella surface, the toothed locking device locks the inclined block to fix the umbrella surface and the vehicle for collecting winter jujubes. Additionally, a miniature motor is used to drive the picking claw to generate exciting force to assist in manual picking. UG modeling and Ansys dynamic simulation of the collection umbrella surface and winter jujube fruits are conducted, simulating the impact of winter jujubes through simulation software to determine the vibration range when the collection umbrella is working. The rationality of its design and its adaptability during operation are analyzed, obtaining average deformation and average stress.

Keywords

Picking and Collection Device; Structural Design; UG Modeling; Ansys Dynamic Simulation.

1. Introduction

China is a major fruit-growing country, and since the 1980s, the planting scale and output of the fruit industry in China have been increasing year by year, gradually surpassing that of European and American countries. There are more than 700 varieties of jujube recorded in China alone, among which the winter jujube is a unique fresh fruit with a glossy and lubricious appearance, crisp and rich fruit skin, and fresh and crispy flesh. Winter jujubes contain abundant trace elements beneficial to human health, which are crucial for human growth, development, and well-being.

The ripening period of winter jujubes is relatively late, so the picking work of winter jujubes is a typical seasonal and labor-intensive task. It is necessary to timely hoe and loosen the soil during winter jujube planting to maintain suitable soil moisture, which is an effective way to improve the later winter production and quality. Typically, winter jujube growers regularly loosen the soil to enhance the root's ability to absorb water and mineral nutrients. However, this can also lead to the soil becoming soft and unable to withstand the entry of heavy machinery. Currently, the design of picking and collecting machinery is limited by weight. Although manual picking is still the most common method, compared to mechanical picking, manual picking has high labor costs, low efficiency, and is not suitable for large-scale, high-intensity planting operations.

There are three main common methods for winter jujube picking at home and abroad: manual picking, suction picking, and vibration picking. Domestic scholars have conducted in-depth research on fruit picking machinery. Sun Jinhua designed a portable winter jujube picking machine; Shang Shuqi et al. designed a vibration-assisted high-acid apple picking machine; Liu Zheng et al. designed a five-degree-of-freedom mechanical arm picking robot for green plum fruits; Liu Fucheng designed a controllable picking force negative pressure suction apple picking system based on metal ducts; Cai Gangyi proposed the design and manufacturing of a high-altitude fruit picking robot for the complexity of fruit picking operations and low automation level; Geng Lei designed a high-bush blueberry picking machine using a hinge four-bar linkage mechanism and a double rocker mechanism and estimated the picking frequency and picking inertial force of blueberry branches.

Overall, the fruit industry has made remarkable progress in China, and there continues to be innovative research and development in fruit picking machinery to address the challenges faced by growers.

Cheng Tangcan et al. used the RB03 six-degree-of-freedom robot as the research object and conducted kinematic modeling and simulation in the Robotics Toolbox platform of MATLAB software to verify the correctness of its kinematic forward and inverse solutions. Research on fruit and vegetable picking machinery abroad has advanced to in-depth studies on picking robots. Since the birth of the first picking robot in the United States in 1983, after more than 20 years of development, developed countries represented by Japan have successively experimented with various fruit picking robots. In the 1990s, Naoshi Kondo and others at Okayama University in Japan designed a mechanical hand with seven degrees of freedom for setting picking postures on a tomato picking robot. However, for winter jujube fruits, robot picking is not suitable for large-scale application.

Currently, there is no widely applicable mechanical equipment suitable for intensive winter jujube planting patterns in China. Existing inventions are limited by factors such as power and volume weight, making them unable to be widely used. Therefore, based on the characteristics of manual picking and mechanical picking, combined with field data, a device for assisting in the manual picking and collection of winter jujubes has been designed. This device is lightweight, low cost, easy to operate, and can effectively reduce winter jujube damage rates and improve picking and collection efficiency.

2. Overall Structural Design of the Picking and Collecting Device

2.1. Winter Jujube Conventionalized Planting Spacing and Requirements for Device Design

Based on research data, the main trunk height of winter jujube trees is typically between 2 to 2.5 meters, with branches carrying jujubes generally ranging from 2.5 to 3 meters in height, and the height without branches on the main trunk is between 0.3 to 0.4 meters. There is no fixed standard for the planting spacing of winter jujubes, but in a standard field, the row spacing is 3 meters, and the distance between rows is between 2 to 3 meters. There are crossovers between branches of adjacent fruit trees, similar to most winter jujube planting spacings. The main trunk diameter of jujube trees ranges from 100 to 140 millimeters, secondary branch diameter is between 25 to 35 millimeters, and tertiary branch diameter is between 8 to 12 millimeters, with jujube fruits only growing on tertiary branches. The soil texture in the jujube orchard is soft and not suitable for heavy machinery operations.

Based on the above data, the requirements for the picking and collecting device can be summarized as follows: the dimensions of the collection cart should be moderate, allowing for free entry and exit from the jujube forest; the height setting and width of the collection umbrella must not interfere with adjacent jujube trees; the length of the picking device should be able to reach fruits both nearby and at height, thus requiring a design that is extendable. Additionally,

ISSN: 2688-8645

due to the soft soil in the jujube orchard, the overall weight of the picking and collecting device needs to be controlled properly.

2.2. Conical Umbrella Collection Device

The composition of this device includes two "7" type rods, four auxiliary rods, a pair of gears, six sprockets, motors, arc transmission device and semi-circular tree clamping device, and one of the "7" type rods welded to the motor's active shaft, the electric motor energized to drive the meshing gears, while the sprocket coaxial with the gear also rotates, through the three chain transmission, to achieve a reasonable arrangement of the transmission chain in space, thus making the two "7" type rods Rotate, at the same time with the gear coaxial sprocket also rotates, through the three chain drive, to achieve a reasonable arrangement of the transmission chain in space, and ultimately the power will be transmitted to the other "7" rod, so that the two "7" rod to achieve the reverse rotation of the motor forwards and backwards. The forward and reverse rotation of the motor drives the forward and reverse rotation of the gears coaxial with the motor, which in turn drives the forward and reverse rotation of the sprocket, realizing the unfolding and closing of the fan cloth.

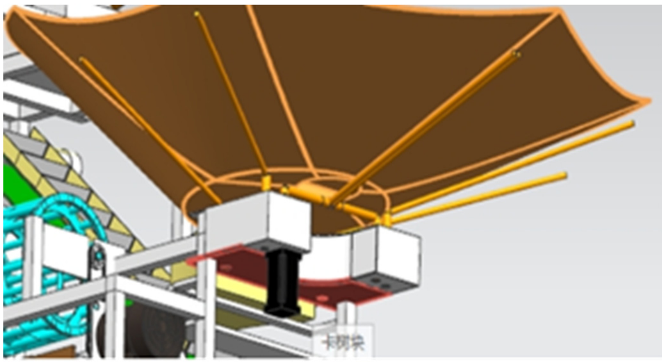

Figure 1. Model view of the conical sector collection device

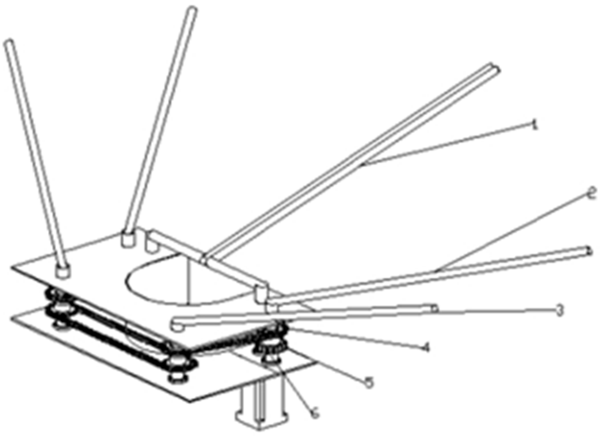

Figure 2. Tapered umbrella collection device

1. "7" bar 2. auxiliary bar 1 3. auxiliary bar 2 4. sprocket 5. gear 6. center shaft

2.3. Design Calculation of Sprocket Wheel

The rated power of the electric motor is P=3kW, the speed of the driving sprocket is n1=90r/min, the transmission ratio is i=1, the load is stable, and the centerline is arranged horizontally. When the chain type is 16A-1; the number of teeth on the sprocket is z_1=21; the number of links LP=100; and the maximum center distance is a_{max}=986mm

ISSN: 2688-8645

3. Specific Component Design and Calculation

3.1. Calculation of the Maximum Deflection of the Parachute Pole

1. Calculation of static load and static deformation

In the umbrella-shaped collection device, the bending deflection of the umbrella pole is particularly important. If the deflection is too large, it will greatly affect the lifespan of the umbrella pole, and may even cause the umbrella pole to break or the upper and lower amplitudes of the umbrella pole to be too large, resulting in the leakage of collected winter jujube fruits. Therefore, it is necessary to check the maximum deflection of the umbrella pole.

The angle between the umbrella pole and the horizontal is 7.4 degrees, and the inclination angle is not large, so the umbrella pole can be simplified as being horizontally placed during calculations. The connection between the umbrella pole and the vertical pole is welded, and the equivalent connection of the umbrella pole is simplified as a cantilever beam model.

A single Zhanhua winter jujube tree can bear 3000 jujubes. It matures three times a year, and only ripe jujubes can be picked at each harvest. By assuming the extreme case, it is estimated that approximately 35 jujubes fall on the umbrella surface at the same instant, with the weight of a single winter jujube being 20g.

Uniform continuous impact dynamic loads can be converted into static loads for calculation. Therefore, the impact generated by the continuous and uniform falling of winter jujube fruits can be considered as a static load.

The umbrella pole is a hollow circular rod with a diameter of 20mm and a wall thickness of 2mm. D=20mm, d=16mm. The umbrella pole is made of 6061 aluminum alloy, with a Young's modulus of 68.9GPa and a density of 0.0000028kg/m3.

Based on the above data: the length of the pole is 1m, and the calculation assumes that at the same instant, 35 jujubes fall on the umbrella surface. The umbrella pole is simplified as a cantilever beam model.

The distributed force acting on a single umbrella pole can be calculated as q = 1.17 N/m.

When the umbrella pole is simplified as a cantilever beam subjected to the action of distributed force, the expression for the deflection curve due to bending is:

$$\omega_3 = -\frac{qx^2}{24EI}\left(x^2 - 4lx + 6l^2\right) \tag{1}$$

In the equation:

q--represents the distributed force acting on a single umbrella pole (N/m).

w3--- represents the deflection deformation of the umbrella pole (mm).

By differentiating the above deflection curve equation, we can determine the maximum deflection which occurs at the end of the cantilever beam.

The expression for the maximum deflection is:

$$\omega_{B2} = -\frac{ql^4}{8EI} \tag{2}$$

The expression for the maximum deflection is given by:

wB2—Maximum deflection deformation of the umbrella pole (mm).

Given the distributed force q=1.67N/m, the length of the pole l=1m, and the elastic modulus E=68.9GPa for the 6061 aluminum alloy.

In order to minimize the weight of the umbrella pole as much as possible to adapt to the relatively soft geological conditions of the plantation, a circular tube is used for the umbrella pole. The formula for calculating the cross-sectional moment of inertia of the umbrella pole is:

ISSN: 2688-8645

$$I_3 = \frac{\pi}{64}\left(D_2^4 - d_2^4\right) \tag{3}$$

In the equation:

I3--represents the moment of inertia of the umbrella pole's cross-section about the central axis.

D2--represents the outer diameter of the umbrella pole (mm).

d2--represents the inner diameter of the umbrella pole (mm).

Given D2=20mm and a wall thickness of 2mm, we can calculate d2=16mm. Substituting these values into the equation, we get I = 4.634×10^-9 m^4.

Substituting the calculated data into the maximum deflection equation, we find that wB2 is approximately 0.653mm.

2. Dynamic load and dynamic deformation calculation

As the process of collecting winter jujubes involves impacting the pole components, the dynamic load on the umbrella pole can be calculated using the impact method for the pole components.

Firstly, the weight of a single jujube is known to be G=0.196N. When 35 jujubes are applied in the form of static load to the umbrella pole, the maximum deflection of a single pole Δst=wB2 ≈0.653mm (static deformation). The static distributed force on a single pole is q=1.17 N/m. The core of this method lies in using the energy method, based on the principle of energy conservation, to determine the deformation and stress under impact load by considering the deformation and stress under static load. The formulas for calculating the dynamic load and dynamic deformation are as follows:

$$F_d = K_d P \tag{4}$$

$$\Delta_d = K_d \Delta_{st} \tag{5}$$

In the equations:

Fd--represents the impact dynamic load.

Kd--is the impact dynamic load factor.

P--denotes the static load.

Δd--stands for impact dynamic deformation.

Δst--represents static deformation.

According to the energy method, the formula for the impact dynamic load factor can be derived as follows:

$$K_d = \frac{\Delta_d}{\Delta_{st}} = 1 + \sqrt{1 + \frac{2T}{P\Delta_{st}}} \tag{6}$$

In the equation:

T--represents the initial kinetic energy of the impact system.

Since the process of winter jujubes falling and impacting the umbrella surface can be considered a free fall process, based on the kinetic energy formula and free fall formula, the equation can be rewritten in the following form:

$$K_d = 1 + \sqrt{1 + \frac{2h}{\Delta_{st}}} \tag{7}$$

Where: h - the height of free fall of jujube.

Substituting the data into equation (7) gives Kd = 71.007. thereby substituting the static load distribution force and Kd into equation (4) gives the impact dynamic load Fd = 83.078N.

4. Mechanical Analog Simulation and Experiment of the Collection Device

In order to verify the size of the stress on the flexible umbrella surface of the collection device when the winter jujube fruit fall impact, as well as the amount of deformation of the flexible umbrella cloth under the impact, in order to determine whether the collection device can withstand the impact of the fruit and whether the amplitude of the umbrella surface is reasonable without affecting the collection work, the use of Ansys software on the impact of fruit on the umbrella surface process of kinetic analysis of the umbrella surface and the winter jujube fruit modeling for dynamic simulation Simulation experiment.

1. Test methodology

In this paper, the designed umbrella surface modeling for the work of the unfolding state, simulation of 35 jujube fruit falling on the umbrella surface, and 35 jujube speed research to get the average height of the average height of the fruit to take the same impact speed, the speed according to the average height of the fruit tree jujube height and the umbrella surface of the height difference with the free-fall formula to find out. In the simulation, the umbrella surface model into Ansys software, to the umbrella surface given its modulus of elasticity, Poisson's ratio, density and other material parameters, to the 35 jujube model given its density, mass and impact velocity, the umbrella surface mesh division after the simulation operation, so as to export its stress and deformation maps, to get the stress and deformation amount.

2. Experimental models

In this paper, the UG software is used to model the umbrella in three dimensions, the unfolding form of the umbrella is simulated to build the model, and 35 winter dates are modeled in the ring above the umbrella and without interfering with it. The model is saved as stp format and imported into Ansys software. This paper mainly analyzes the stress and umbrella surface deformation generated by transient impact, and applies the corresponding linear constraints at the corresponding pole position of the umbrella fabric to achieve a similar effect with the pole support on the umbrella surface, but because the actual umbrella pole will also generate up and down vibration, which will produce a cushioning effect, and therefore the deformation generated in practice will be smaller than the experimental simulation value.

Thirty-five jujube models are modeled in a ring at 0.03 mm above the umbrella surface and are given the final velocity at which they will eventually contact the umbrella fabric, of which the specific simulation setup parameters and simulation models are as follows.

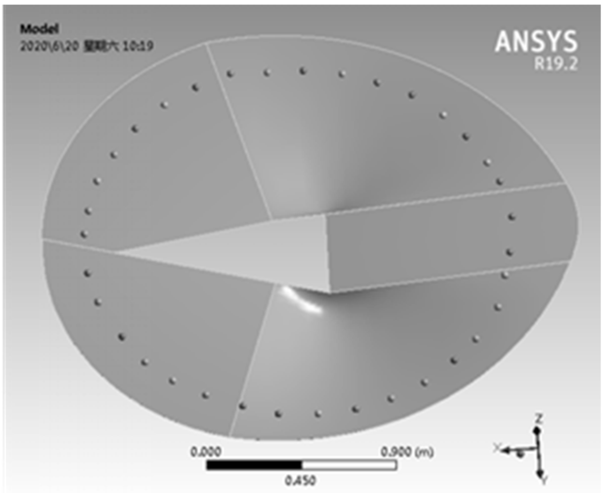

Figure 3. Modeling of flexible umbrella cloth and jujube fruit

The material parameters of the collection umbrella are set as follows. The unfolded area of the collection umbrella surface: 4.497m2; the material of the umbrella surface: polyester fabric; the elastic modulus of the umbrella surface: 9.79 GPa=9.79*109pa; the Poisson's ratio of the umbrella surface: 0.3; the density of the umbrella surface: 1.2g/cm3; the height of the umbrella surface from the ground: 0.4m.

The material parameters concerning the dates are set as follows. There are jujube distance from the average height: 2m; jujube impact umbrella cloth speed: 5.5821m/s; the number of jujube: 35; individual jujube fruit mass: 20g; jujube density: 0.906g/cm3; jujube volume: 22.067cm3; jujube Poisson's ratio: 0.394 (brittle ripening period jujube); jujube movement time is 0.015s.

3.1Simulation experiment results

After the simulation model is given the corresponding parameters, and the umbrella surface is divided into grids, according to Ansys simulation simulation of the dynamics of the model, 35 jujubes are dropped at an average height of 2 meters, and the action time is 0.015s, when the impact of flexible umbrella cloth of jujubes is generated by the stress cloud diagram as shown in Fig. 4.

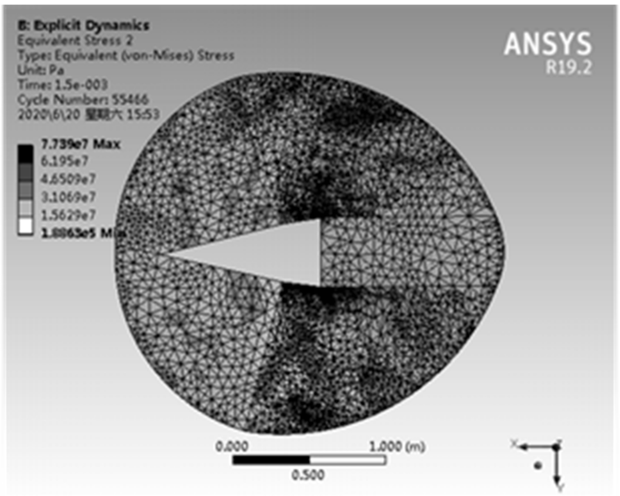

Figure 4. Simulated stress cloud

The figure shows that the maximum stress of the impact is 7.739*107 Pa, the minimum stress is 1.8863*105 Pa, and the average stress is 1.1008*107 Pa.

In addition, the deformation cloud diagram of the flexible umbrella fabric after the impact occurred for 0.015 s was also obtained as shown in Fig. 5.

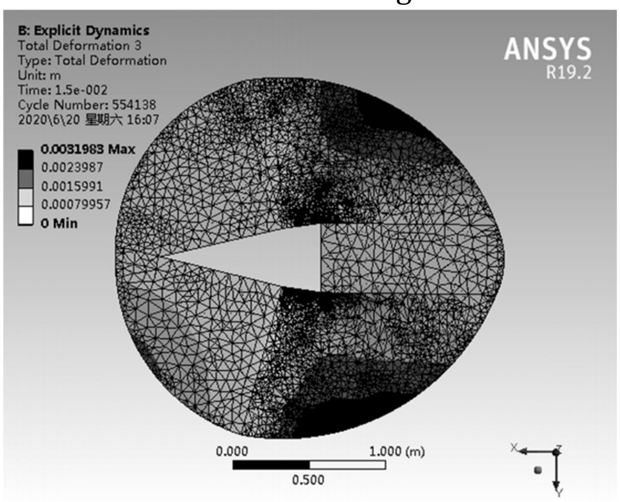

Figure 5. Simulation of parachute deformation cloud

It can be seen that the maximum strain occurs at the edge of the umbrella cloth, and the maximum deformation is only 3.19mm, and the calculation shows that the average deformation is 9.7097*104 m or 0.97mm, in which it can be seen that the maximum deformation occurs at the edge of the umbrella cloth, which is in line with the design concept. This strain occurs at the edge of the flexible umbrella cloth, which means that the edge of the umbrella cloth only produces a small shake of 0.97mm on average when collecting, and this shake is so small that it not only does not have an impact on the collection, but also provides a buffer function for the fall of the dates in order to play a protective role for the fruits of the jujube. And this simulation modeling 35 jujube in the same instant impact umbrella surface is a large degree of assumptions, the actual picking and collection work, a branch on the winter jujube fruit is rarely more than this number, and at the same time fell to the umbrella surface of the winter jujube is less than 35, and the production of the umbrella surface will also be added to a variety of coatings, in order to improve the impact resistance of its ability to umbrella surface, umbrella under the umbrella more support for umbrella poles, the actual umbrella cloth deformation and stress value Therefore, the deformation and stress value of umbrella fabric in practice will be less than the above values. The design of the umbrella is within the safe range.

5. Conclusion

According to the actual situation of Zhanhua winter jujube plantation and the existing picking machinery, a lightweight vibration type winter jujube picking collection device is designed. The device consists of rope stretching umbrella surface collection device, retractable vibration drop auxiliary picking claw and tooth-shaped locking device, simple structure, easy to operate. It mainly adopts human power to drive the rope line stretching, drive the torsion spring to rotate the umbrella pole to realize the umbrella surface unfolding, and at the same time, it fixes the umbrella surface and the car body through the tooth-shaped locking device by jamming the inclined block, which is used to collect the winter jujubes. Secondly, the micro-motor is utilized to drive the picking claw to generate vibration force to assist manual picking. This device is practical and lightweight, with advantages such as simple operation. Under the intensive planting mode of Chinese jujube plantation, through the artificial handheld picking mechanical claw hanging down, assisted by the vibration of jujube, through the fixed self-locking collection car open flexible umbrella cloth to collect jujube fruits, can effectively improve the efficiency of jujube picking under the premise of ensuring low damage rate, is conducive to the fast and lightweight development of jujube picking and collection work.

In addition, UG modeling and Ansys dynamics simulation were carried out for the collection umbrella and jujube fruits, and the impact of jujube was simulated by the simulation software to determine the vibration range of the collection umbrella when it was working, and its design rationality and adaptability when it was working were analyzed, and the average deformation and average stress were obtained to be 0.97 mm and 1.1008*107 Pa, respectively.

References

[1] H.Q. Xu. Research on Intelligent Dynamic Optimal Selection Equipment for Winter Jujube Based on Convolutional Neural Network[D]. Qingdao University of Science and Technology, 2023(6):1-3.

[2] M Wang, X.G Pang. Relationship between Quality of Zhānhuà Winter Jujube and Trace Elements[J]. Anhui Agricultural Sciences(36):20674-20676,20679.

[3] K F Sanders. Orange Harvesting Systems Review[J]. Biosystems Engineering, 2005, 90(2):115-125.

[4] Z.j. Gao. Management Before and After Winter Jujube Harvesting[J]. Friends of Fruit Growers, 2006 (11): 49-49.

[5] Z Zhang. Research on Vibration Harvesting Device of Yā Winter Jujube[J]. Journal of Jiangsu College of Engineering (Comprehensive Edition), 2020(3):1-1.

ISSN: 2688-8645

[6] J.H. Sun, Design of Winter Jujube Harvesting Machine[J]. Scientific Research on Agricultural Machinery, 2024,139:1-1.

[7] S.Q. Shang, Chen Li, X.N. He, et al. Design and Test of High Acid Apple Vibration Picker[J]. Transactions of the Chinese Society for Agricultural Machinery, 2023, 54(3):1-1.

[8] Z. Liu, Y Liu, L.X. Shen. Design of Qingmei Picking Robot[J]. Forestry Machinery and Woodworking Equipment, 2019(10):23-28.

[9] F.C. Liu, J.H. Huang. Negative Pressure Suction Apple Picking System Based on Metal Conduit[J]. Hubei Agricultural Mechanization, 2019(16):121-121.

[10] G.Y. Cai, H.H. Weng, H.Y. Zhou. Design of High-altitude Operation Fruit Picking Robot[J]. Light Industry Machinery, 2016(1):76-78.

[11] L Geng, Y.L.Guo, H.B Wang, et al. Design and Test of High-bush Blueberry Picking Machine Picking System[J]. Transactions of the Chinese Society for Agricultural Machinery, 2016, 47(3):67-74.

[12] T.G. Cheng, F.S. Zhang, H Wang. Analysis and Simulation of Motion Characteristics of Picking Robot Based on MATLAB[J]. Machine Tool & Hydraulic, 2019(11):29-34.

[13] F. Lan, Z.H. Su, Z.M. Li, et al. Discussion on Research and Development of Orchard Picking Machinery at Home and Abroad[C]// Sub-venue of International Agricultural Engineering Conference "Twelfth Five-Year Plan" Low-carbon Agricultural Equipment Technology Innovation Research. 2010.

[14] L.P. Jiang, S.R. Chen. A Review of Research on Fruit Picking Robots[J]. Agricultural Equipment Technology, 2006(1):8-10.

[15] H.J. Zhang, J.W. Wang Calculation and Analysis of Several Common Eccentric Block Eccentric Moments and Excitation Forces[J]. Mining Machinery, 1999(6):68-68.