Design and Simulation of Adsorption Citrus Picking Actuator

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Abstract: In order to realize mechanized citrus picking, an adsorption type non-destructive citrus picking end effector was designed based on the basic characteristics of citrus, which is mainly composed of three parts: shearing mechanism, adsorption mechanism and transmission frame. The three-dimensional model of the end effector is established, and its kinematics simulation and finite element simulation analysis are carried out to ensure the rationality of the mechanism design and material selection. The simulation results show that the structure design and motion characteristics of the end effector are reasonable, which can basically meet the needs of citrus picking.

1 INTRODUCTION

Citrus is one of the pillar industries of agriculture in the hilly areas of southwest China. At present, it has become an important supporting industry for Chengdu Chongqing Economic Circle to build a characteristic and efficient agricultural system. However, the level of agricultural mechanization in hilly areas is low, and the cost of manual picking accounts for more than 30% of the total cost of citrus. In addition, with the serious problems of industrialization development and population aging in China, citrus picking costs will further increase, so agricultural mechanization in hilly and mountainous areas is imminent (Zhang, 2019; He, 2018; Li, 2008).

Experts and scholars at home and abroad have carried out more in-depth research on automatic fruit and vegetable picking machinery, among which Johan Baeten, Davidson, etc. have analyzed apple machine picking and designed corresponding picking actuators (Baeten, 2008; Monta, 1998); In addition, Han Shukui (Han, 2019) Liu Yue (Liu, 2014), Xu Liming (Xu, 2018), Yang Wenliang (Yang, 2019) , Zeng Wen (Zeng, 2019) and others have studied the citrus picking problem and its picking actuator. Among them, a hairdresser pusher picking end actuator from Kubota (Kubota, 2009), Japan, a picking robot based on snake like swallowing principle from Fu Shun (Fu, 2017), and an underactuated three finger picking end actuator from Wu Jijun (Wu, 2018) are very representative.

At present, the main problems of citrus picking robot are long picking time, low efficiency and high damage rate. Therefore, this paper designs an end effector for the non-destructive harvesting of ancient red tangerine, and uses the finite element method to carry out simulation analysis.

2 STRUCTURE DESIGN OF ADSORPTION END EFFECTOR

2.1 Basic Physical Characteristics of Citrus

Randomly select 100 ancient red oranges and ponkan oranges with different shapes and sizes, measure the transverse diameter, longitudinal diameter and fruit stem diameter of ancient red oranges and ponkan oranges with vernier calipers, and count the largest and smallest fruit stem diameter, and the transverse diameter and longitudinal diameter of oranges. Use the electronic scale to measure their mass and count the maximum mass and minimum mass. After measurement, the average weight of the ancient red orange is 88g, the average transverse diameter is 53mm, the average longitudinal diameter is 45mm, and the average diameter of the fruit stalk is 2.1mm.

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Table 1: Measurement results of parameters of Citrus.

parameter	maximum	minimum	average
quality（g）	127	62	88
Transverse diameter（mm）	65	46	53
longitudinal diameter（mm）	58	36	45
diameter of the fruit stalk（mm）	2.5	1.7	2.1

Figure 1: Separation experiment of citrus fruit and stem.

2.2 Basic Mechanical Properties of Citrus

Take 50 oranges, connect the hook of the dynamometer with the fruit stem of the citrus through an inelastic rope, and slowly pull the tension meter at a constant speed until the fruit stem and the fruit are separated. The maximum force required to separate the fruit from the peduncle is 46.2N, and the minimum force is 21.9N.

Cut the fruit stem by simply supported beam and measure the required shear force (as shown in Table 2), and the maximum cutting resistance required is 79.2N.

2.3 Structure Design of Adsorption Citrus end Effector

In combination with the above citrus related parameters, an adsorption type citrus non-destructive picking end actuator is designed as shown in Figure 2, which is composed of three parts: a shearing mechanism, an adsorption mechanism and a transmission frame.

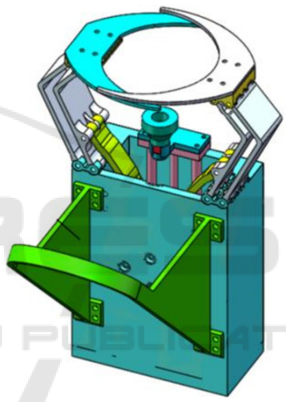


Figure 2: Three-dimensional model of adsorption end-effector.

Table 2: Experimental data of fruit stem cutting.

diameter of the fruit stalk (mm)	maximum cutting resistance(N)	diameter of the fruit stalk(mm)	maximum cutting resistance(N)
1.9	47.5	2.1	71.3
3.0	77.8	2.1	59.8
2.3	67.9	3	79.2
2.4	56.4	2.8	63.5
2.5	63.5	2.1	67.3
2.8	62.8	2	72.5
2.7	53.5	2	75.3
2.6	63.3	1.9	53.8
2.9	71.5	2.7	62.6
2.2	66.2	2.0	67.3

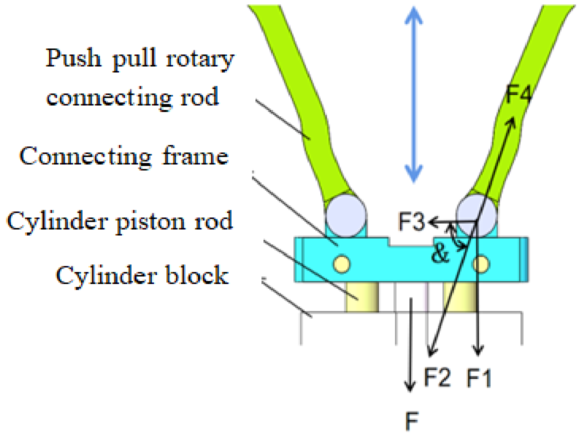


Figure 3: Partial drawing of shearing mechanism.

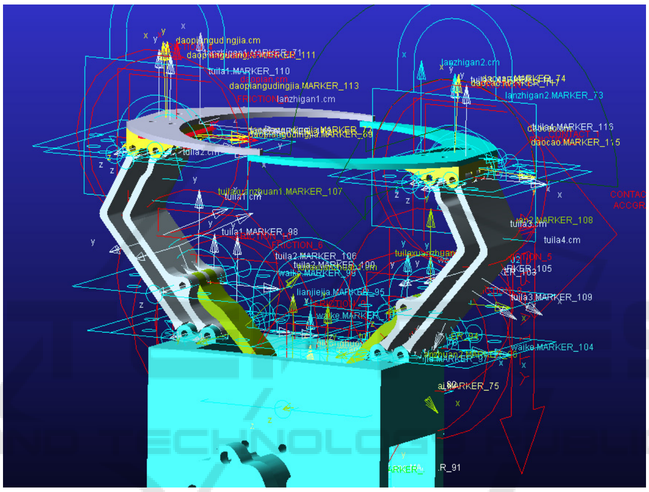


Figure 4: Parameter setting

2.4 Key Structure Design of Actuator

The shearing mechanism is designed based on the parallelogram connecting rod mechanism. The piston rod pulls the parallelogram mechanism to move symmetrically towards the center, and the blade moves in parallel with the knife slot to cut the citrus fruit stalks.

At the moment of shearing by the shearing mechanism, the angle is about 60°, and the maximum cutting resistance of citrus is 79.2N. Calculate the tensile force F according to Figure 3.

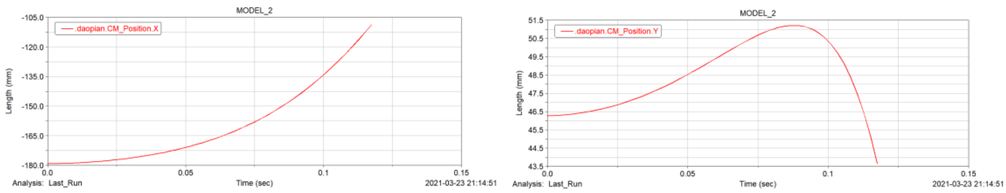
$$F=2F_1\approx 137\text{N}$$

Combined with the actual environment, the pneumatic double rod cylinder TN16.10 with a 0.5MPa air pressure pull of 150.8N is selected as the cylinder in the shear mechanism.

3 FINITE ELEMENT SIMULATION ANALYSIS OF END ACTUATOR

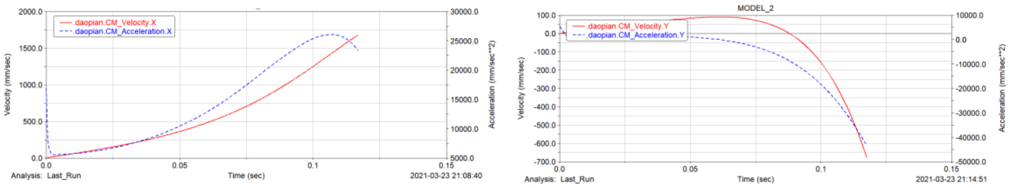
3.1 Dynamic Simulation Analysis of end Actuator

Use Adams software to carry out kinematics simulation, create constraints and define the material property as high manganese steel 7.98×10^{-3}g/m3, 2.06×10^{5}N/mm^2, Poisson's ratio 0.26; Steel 7.801×10^{-3}g/mm3, 2.07×10^{5}N/mm^2, Poisson's ratio 0.29. Load 150N tension on the cylinder piston rod to drive the



(a) (b)

Figure 5: Displacement curve of blade in X and Y direction.



(a) (b)

Figure 6: Velocity and acceleration curve of blade in X and Y direction.

Table 3: Material Properties.

material	density（g/mm^3）	Young's modulus（N/mm^2）	Poisson's ratio
（stem) Branch	0.000438	11000	0.33
（blade）Permanganate steel	0.007980	206000	0.26
（connecting link） steel	0.007801	207000	0.29
（connecting link）pla	0.00121	3000	0.35

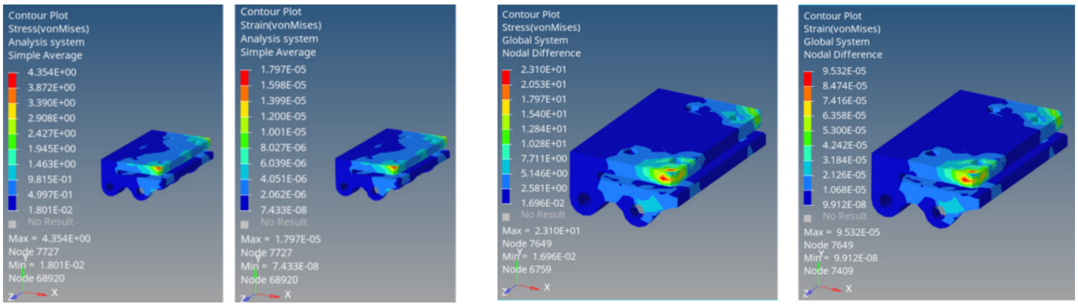
shear mechanism to move, and finally obtain the force, speed and acceleration curves in the movement process.

According to the analysis of the displacement, speed and acceleration of the blade, the maximum distance of the blade moving in the X direction is about 70mm, the maximum distance in the Y direction is about 7mm, and the maximum distance of the cylinder in the Y direction is 10mm; Under the tension of 150N, the speed and acceleration of the blade are smooth curves without obvious instantaneous impact, so the mechanism of the picking end actuator is well stressed, without movement interference, and the structure is reasonable.

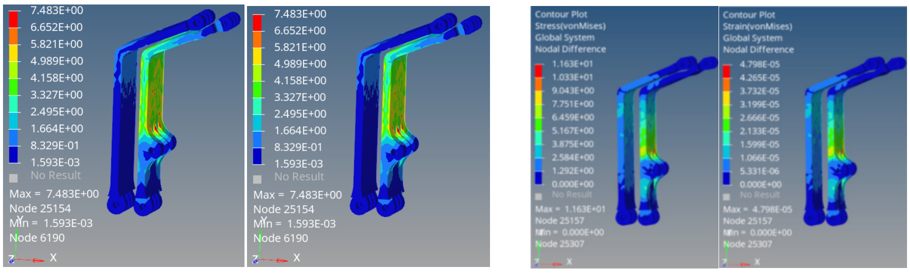
3.2 Stress Analysis of the Actuator at the end of Citrus Picking

Use ansys and Hyperworks for stress analysis. In order to obtain more accurate data, the grid of the fruit stem and blade is densified, and the tension on the connecting frame is set to 150N. As shown in Table 3, the material properties of the blade, fruit stem and connecting rod are set, and the corresponding stress and strain are obtained after solving.

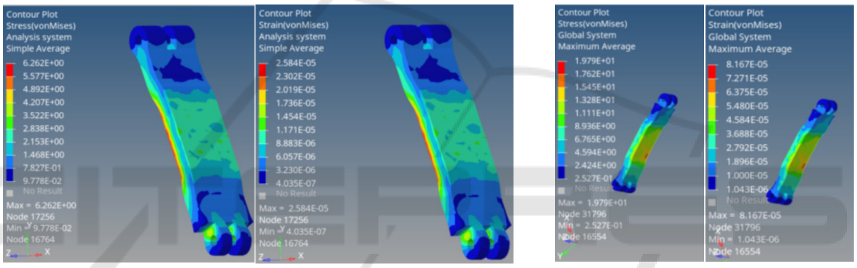
The stress and strain nephogram of the connecting rod and tool holder made of steel is shown in a in Figure 7a. It can be clearly seen that the maximum stress of the tool holder is 4.354MPa and the maximum strain is 1.79×10^{-5}; The maximum stress of the rotary connecting rod is 7.483MPa, and the maximum strain is 3.089×10^{-5}; The maximum stress of the connecting frame is 7.472MPa, and the maximum strain is 3.084×10^{-5}; The maximum stress of push pull rotary connecting rod is 6.262MPa, and the maximum strain is 2.584×10^{-5}; Therefore, the maximum stress of the whole actuator frame is 7.483MPa, and the maximum strain is 3.089×10^{-5}, which is far less than the yield strength of steel from 200MPa to 400MPa. In order to reduce cost and lightweight, the alternative verification of pla material with yield strength of 48MPa is shown in Figure 6b.



Tool holder stress and strain



Stress and strain of rotary link



Stress and strain of push-pull rotary connecting rod

(a) steel products (b) pla products

Figure 7: Key parts stress and strain.

The analysis of the stress and strain nephogram of the mechanism made of pla material shows that the maximum stress on the tool holder is 23.10MPa, and the maximum strain is 9.532×10^{-5}, according to the yield strength of the pla material, the safety factor n=1.5 is selected, and the following is calculated:

$$\sigma_{smax} = 23.10MPa < \frac{\sigma_s}{n} = 32MPa < 48MPa$$

Therefore, the tool holder uses pla material. Similarly, the strength of rotary connecting rod, shell, push-pull rotary connecting rod and other parts meet the design requirements. Pla material can be used instead of steel.

4 CONCLUSION

According to the requirements of non-destructive picking and the basic physical characteristics of ancient red tangerine, an adsorption type end effector for non-destructive picking of ancient red tangerine was designed and simulated and optimized using finite element method. The prototype manufacturing of the adsorbed ancient red orange non-destructive picking end actuator was completed, and the adsorption performance and shear performance of the prototype were verified. The non-destructive picking function of the adsorbed ancient red orange picking end actuator was realized, which provided conditions for the subsequent overall assembly test of the intelligent orange picking robot.

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CONFLICTS OF INTEREST

The authors confirm there is no conflict of interest.

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