Structural Design and Analysis of a Multi-Functional Carrot Picking Robot

Shuo Li †, Jiawei Gui *,†, Mingbo Zhang

School of Mechatronic Engineering, Xi'an Technological University, Xi'an, China, 710021

* Corresponding Author Email: 13755774554@139.com

† These authors contributed equally.

Abstract. Aiming at the problems of low harvesting efficiency, low automation degree and single function of the current carrot harvesting machinery, the article developed and designed a carrot picking robot with high degree of intelligence and various functions. First of all, the article put forward the overall design program of carrot picking robot. Then, solidworks modeling software was used to design the overall design of the robot mechanical structure. In addition, the design of the robot is perfected with theoretical calculations. Finally, the robot prototype software debugging and performance and other experimental tests are completed. The results show that the various performance experiments of the carrot picker meet the working requirements and can achieve the complete picking of radish.

Keywords: Carrot, Picking Robot, Three-Dimensional Structure.

1. Introduction

The planting area and output of carrot in China ranks first in the world. However, the mechanization level of carrot is relatively low [1-2], and the current harvesting method is still mainly artificial, with a few semi-mechanized operations, resulting in low harvesting efficiency, large labor demand and low intelligence [3-4] and other problems. Western countries such as Europe and the United States are mainly carrot planting, and the research of the combine harvester started early, the technical development level is high, and the mechanization and automatic picking are basically realized.

Qingdao Agricultural University developed a self-propelled carrot combine with a harvesting row spacing of 20cm and a maximum digging depth of 35cm [5].

Northeast Agricultural University developed a carrot combine with a single disc top cutting device, which solved the problems of high damage rate and low cutting rate during carrot top cutting [6]. Aiming at the planting mode of green radish in China, Shandong Agricultural University designed a notch disc radish combine harvester that can automatically raise the cutting edge and dig rows by using regression analysis and discrete element simulation verification methods based on the harvesting experience of other root crops [7]. Fan Wei from Guizhou University designed a hand-held white radish harvesting machine suitable for the topography of hilly and mountainous areas in Guizhou, and determined the relevant parameters of the machine during operation, which has played a good role in the white radish harvesting operation in southwest China [8]. The CH-201C radish harvester developed by Kubota, Japan, uses L-type shovel to loosen soil, which has high efficiency and reliable operation [9]. South Korean Li Hanning et al. developed a radish harvester with a modular and multi-purpose drive platform, and evaluated the field efficiency and loss rate of the performance of the multi-purpose drive platform [10]. However, these harvesting machines are relatively large. China's terrain is more complex, radish planting area is mostly small plot planting, planting area is not contiguous and widely distributed, so it is not suitable for the use of large harvesting machinery. In this paper, the large-scale harvesting machine described in the above literature is improved, and a small radish harvester suitable for mountainous work is designed.

Based on the analysis of the planting environment, growth characteristics and harvesting characteristics of carrots, this paper designs the principle scheme of the robot, and uses solidworks for structural design through calculation and analysis, aiming to complete the integration of carrot harvesting, seedling removal, collection, unloading and other multi-process operations at one time, so as to improve work efficiency.

2. Robot Functional Requirements

The robot designed in this paper is different from the previous carrot harvester, combined with the current pain point problems in this field, the following main functional requirements: the need to achieve fully automated and unmanned operation; autonomy to complete the entire process of carrot harvesting; to achieve the automatic adjustment of the harvesting depth, automatic cleanup of soil, autonomous cutting stems, and automatic loading and unloading of grain and other functions.

3. Robot structural design

3.1. Robot overall structure design

Its overall structure is shown in Fig 1, which is mainly composed of 4 major parts: 1. traveling ground 2. harvesting structure assembly 3. cleaning part assembly 4. collection structure assembly.

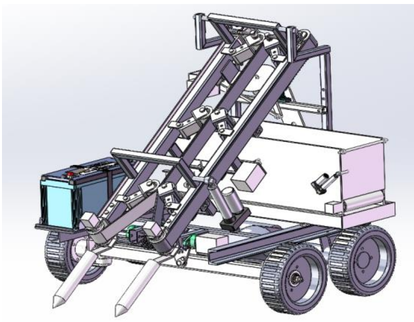

Figure 1. Robot overall structure

The carrot harvesting robot adopts pure electric drive, which can realize stepless adjustment of travel speed and free switching of travel direction, and is also easy to be controlled by the navigation system to realize automatic travel of the whole machine.

Its working principle is as follows: after the robot enters the field, it first loosens the soil on the side of the carrot by using the digging assembly at the front end, and then the plucking conveyor belt of the extractor grips the stems and leaves, pulls the carrot out of the soil, and transmits upward, and the rotating brush removes the soil of the root of the carrot in its upward movement, and the oscillating mechanism passes through the left and right to shoot the soil of the rest of the carrot, and finally the tassel-cutting device is used to cut the tassels of the carrot by the tassel-cutting device. The tassel cutting device removes the stems on the carrots via the carrot, and the carrots fall into the collection box, completing the picking process.

3.2. Traveling chassis design

The traveling ground is mainly composed of frame, driving axle, steering axle and so on, and its structure is shown in Fig 2. The main function of this mechanism assembly is to drive the whole machine to travel.

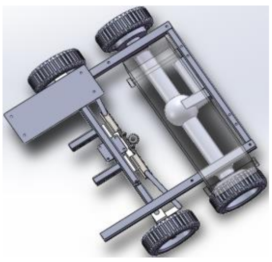

Figure 2. Traveling Chassis Diagram

3.2.1 Steering axle design

The steering axle consists of the main beam, remote pendulum frame, left and right ramshorn axles, wheel hub, steering rack and pinion, steering tie rods and so on. Its structure is shown in Fig 3.

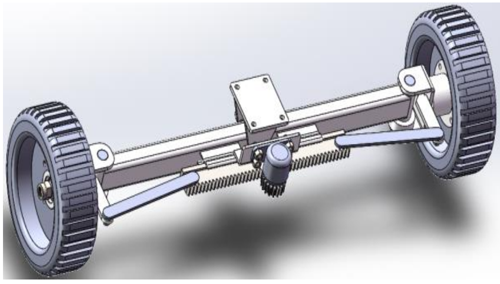

Figure 3. Steering axle structure

3.2.2 Structural design of the drive axle

The structure of the drive axle is schematically shown in Fig. 4:

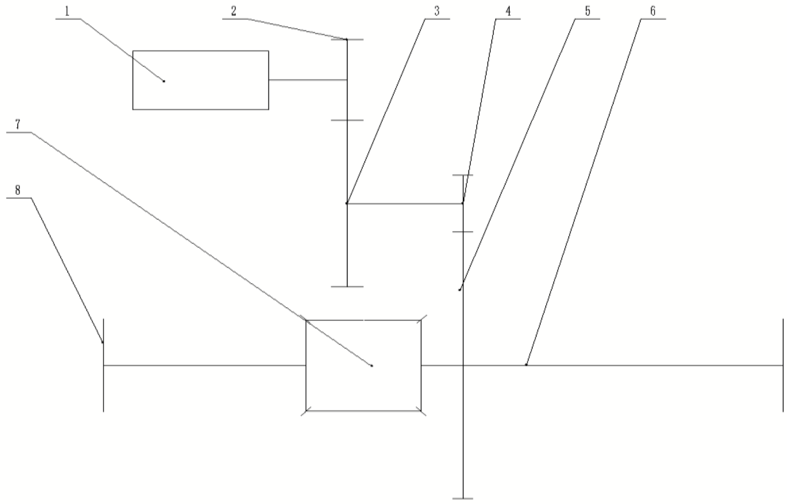

Figure 4. Schematic diagram of drive axle structure

The numbers in Figure 4 represent the individual components of the drive axle. 1. drive motor, 2. primary reduction pinion, 3. primary reduction gear, 4. secondary reduction pinion, 5. secondary reduction gear, 6. right half shaft, 7. Reducer, 8. left half shaft.

3.2.3 Design of frame structure

The frame is an important part to support the whole machine, which is welded by square tube and channel steel as well as part of steel plate, and the steering axle, driving axle, battery, controller and other parts are installed on the frame, whose structure is shown in Fig 5, which is easy to disassemble, maintain and replace by using bolts to connect with the frame. The harvesting part is also connected to the frame by bolts, which can realize the multi-purpose, when the harvesting part is removed, the machine can be turned into a transport vehicle.

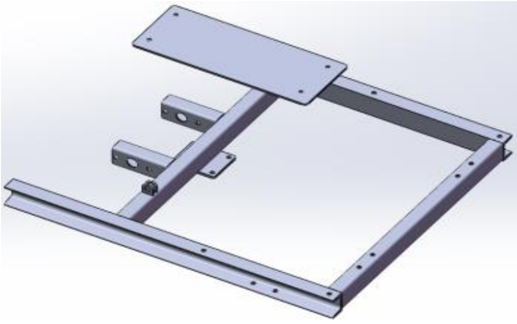

Figure 5. Frame structure diagram

3.3. Harvest assembly design

Harvesting structure is mainly composed of the active wheel, driven wheel, tensioning device and belt, etc., harvesting operation of the lowest point of the plucking clip from the ground height adjusted to the appropriate position, this paper design harvesting structure can be adjusted by the electric actuator to adjust its height, the rear end of the pivot type, through the bracket is fixed to the frame, the adjustment of the height of the height at the same time, but also adjusted the plucking clip and the angle of the ground.

3.4. Clean up part of the assembly

As shown in Fig. 6 the cleaning part consists of a swing motor, a small swing arm, a large swing arm, a swing disk, a swing bearing seat, a swing shaft and so on.

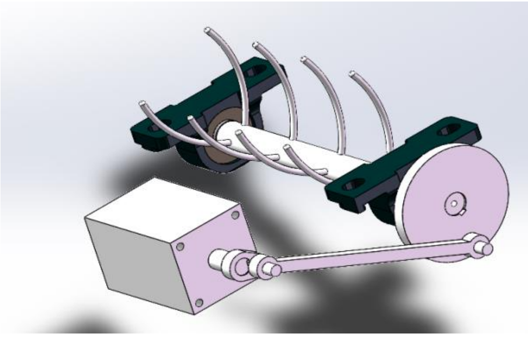

Figure 6. Map of the clean-up section

In this paper, the design of the cleanup part of the motor's axis is 48.3mm higher than the center of the swing axis, the motor axis and the center of the swing axis of the horizontal distance of 195mm. the small pendulum arm length of 15mm, the large pendulum arm length of 200mm, the swinging disc of the swinging radius of 40mm around the swing amplitude of 21.5 degrees for each.

3.5. Structural design of collection box

The collection box consists of chute, box, conveyor belt, side door, collection box swinging crank linkage and so on. The collection box can catch the falling radish, if the collection box is not used, the radish will fall to the ground, which will waste labor or use the machine for secondary collection, affecting the operational efficiency. One of the innovations of this design is that the crank linkage mechanism can be moved left and right, so that the utilization rate of the collection box can be as high as 80%, which reduces the number of times of unloading grain and greatly improves the operational efficiency. In order to realize the full unmanned operation, the unloading of the collection box is designed to automatically open the side door and conveyor belt automatic unloading, the side door oil electric actuator push to realize the opening and closing, the conveyor belt is driven by the motor to open the door and then the motor rotates to unload the radish to the soil, or bagging by hand.

4. Motor Selection

4.1. Drive Axle Motor Selection

Different varieties of radish planting row spacing is different, generally 40-60cm, this design chooses 50cm planting row spacing. Therefore, the maximum traveling speed of the whole machine is V=6.5km/h.

The net weight of the robot designed in this paper is about 220kg, and the weight of fully loaded radish is estimated to be 70kg according to the capacity of the collection box, so it is calculated and selected according to the maximum fully loaded weight of 300kg.

$$P_1 = \frac{v_{max}}{3600 \cdot \eta_1}\left(mgf + \frac{C_D A {v_{max}}^2}{21.15}\right) \tag{1}$$

$$P_2 = \frac{v_{max}}{3600 \cdot \eta_1}(mgf cos\alpha_{max} + mgsin\alpha_{max} + \frac{C_D A v_{max}{}^2}{21.15}) \tag{2}$$

Where: for the full load mass of the harvester, the value is; for the rolling resistance coefficient, take the value; for the wind resistance coefficient, due to the small speed, so do not consider the air resistance; for the windward area; for the maximum speed, take the value; for the mechanical system transmission efficiency, take the value; for the maximum climbing degree, take the value;, respectively, for the maximum speed of the power corresponding to the maximum climbing degree corresponding to the power of the unit is.

Calculated to get: $P_1 = 8.1$kw, $P_2 = 8.9$kw.

Therefore, the selected motor power is taken as 8.9kw, and the rated speed of the motor is 2975r/min.

4.2. Steering Motor Selection

The resisting moment of the radish harvester for in-situ steering is calculated by the formula

$$T_W = \frac{\mu}{3}\sqrt{\frac{G_1^3}{P}} \tag{3}$$

Where G_1 is the load of the steering axle, N; is the friction coefficient between the wheel and the ground, take 1.4; P is the tire pressure, Mpa, T_W is the in-situ steering torque, Nmm.

The steering axle load is G=150kg*9.8=1470N, tire air pressure takes the value of 0.2Mpa, calculated T_W=58812Nmm, the steering force arm length L_3 designed in this paper is 114mm, and the steering tension F_3 of the rack and pinion is

$$F_3 = \frac{T_W}{L_3} = \frac{58812}{114} = 515.89N \tag{4}$$

This design selects the steering angle of 50 degrees, under this angle, the distance moved by the rack is 96mm. the time taken to turn from the center to the side of the maximum angle is 1s, the speed of the rack moving speed V_3=0.096m/s, the power of the steering motor P_3 is

$$P_3 = \frac{F_3 \times v_3}{0.85} = \frac{515.89 \times 0.096}{0.85} = 58.26\text{kw} \tag{5}$$

Where: 0.85 is the power reserve value. Therefore, the power of the steering motor is selected as 60 KW. The gear in the rack and pinion designed in this paper is 17 teeth module 3 and the diameter of the indexing circle D=51mm.Then the rotational speed of the steering motor is

$$\omega_2 = \frac{V_3 \times 1000}{\pi D} \times 60 = 35.96 r/\min \tag{6}$$

Therefore, the steering motor selection is 60W, 40 r/min.

4.3. Clamping conveyor motor selection

The clamping force of the extraction clamp should be satisfied:

$$N_2 f \geq N_1 \tag{7}$$

Where N2 is the clamping force of the plucking clamp, N; f is the friction coefficient between the stem and leaf and the plucking clamp, and 1.4 is selected here.

Calculated that the clamping force of the extracting clamp is 21.4N, which is the minimum clamping force needed to extract the radish, you can select the appropriate tension spring according to this parameter, in addition to selecting a larger friction coefficient of the conveyor belt, the clamping force of the spring should not be too large, so as not to wear out the conveyor belt too quickly.

When the vehicle speed is fixed, the speed of the conveyor belt should be able to ensure that all the radishes are clamped, and the speed of the conveyor belt V2 should satisfy the formula:

$$V_2 \geq \frac{V}{\cos\alpha} \tag{8}$$

Where, V is the vehicle speed, 1.85m/s

α is the angle between the plucking clip and the ground, the machine is designed 40 degrees Calculated to get V_2 = 2.42m/s.

The average weight of a single carrot is about 0.1kg, and the planting spacing of carrots is about 10cm.

As shown in Fig 7, the distance from the beginning of the chain to start clamping to the back side of the knife plate to separate the carrot tassel from the carrot is 954mm, according to the diagram, the theory of this distance can be clamped 8 carrots.

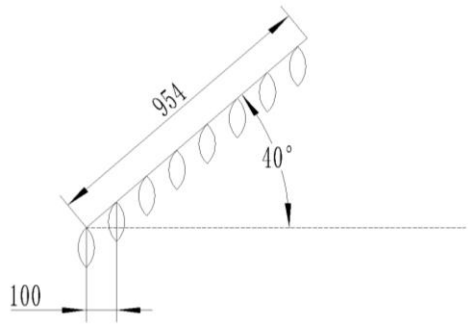

Figure 7. Schematic Diagram of the Clamping Part

Therefore, the power of the conveyor belt can be divided into two aspects, on the one hand, with the radish backward, on the other hand, with the radish to the high side, and the power to pull up the radish.

The power P4 going backward is

$$P_4 = 8mgV = 8\times 0.1\times 9.8 * 1.85 = 14.5w \tag{9}$$

The power P5 going up is

$$P_5 = 8mgV\tan 40° = 8\times 0.1\times 9.8\times 1.85\times \tan 40° = 12.12w \tag{10}$$

The power P6 for pulling up the radish is

$$P_6 = N_1 \times V\tan 40° = 46.6w \tag{11}$$

So the power required by the conveyor belt Pd is

$$P_d = \frac{P_4 + P_5 + P_6}{0.8} = 91.5w \tag{12}$$

Since there is one motor for each conveyor belt, the power of each motor is 45.75w, so a 50w motor is chosen.

5. Conclusion

This paper researches and designs a new carrot harvesting robot, which can complete the harvesting, seedling removal, collection, unloading and other operations of carrots at one time. The structure comprehensively utilizes the rack and pinion mechanism, crank linkage mechanism, bevel gear mechanism, differential mechanism, and chain transmission mechanism, which makes the robot work smoothly and efficiently, and at the same time carries the autonomous navigation control system, which effectively solves the problems of low harvesting efficiency, low automation degree, and single function, etc. The robot is equipped with the autonomous navigation control system. At the same time, it is equipped with an autonomous navigation control system, which effectively solves the problems of low harvesting efficiency, low automation degree and single function.

References

[1] LI Jing, ZHANG Gangzhao, HU Kai et al. Structural design of carrot harvester [J/OL]. Agricultural Equipment and Vehicle Engineering, 1-6 [2024-03-22].

[2] LIU JOSHI, SHAO Wenjuan. Structural design of automatic carrot harvester [J]. Manufacturing Automation, 2022, 44 (06): 80-82+165.

[3] WANG Jinwu, GUAN Rui, GAO Pengxiang et al. Design and test of a single disk to top cutting device for carrot combine harvester [J]. Journal of Agricultural Machinery, 2020, 51 (09): 73-81.

[4] Gao Pengxiang. Research on online detection method of carrot surface defects based on deep learning [D]. Northeast Agricultural University, 2022.

[5] WANG Fangyan, GAO Sheng. Comparative experimental study on mechanical properties of typical radish [J]. Agricultural Mechanization Research, 2019, 41 (04): 166-169.

[6] WANG Jinwu, GUAN Rui, GAO Pengxiang et al. Design and test of a single disk-to-top cutting device for carrot combine harvester [J]. Journal of Agricultural Machinery, 2020, 51 (09): 73-81.

[7] Liu Qiang. Design and research on key components of excavated radish combine harvester [D]. Shandong Agricultural University, 2019.

[8] Fan W. Design and experimental research on key components of small self-propelled white radish harvester [D]. Guizhou University, 2022.

[9] Yao Shuai, Miao Lei, Tan Jun et al. Research status and development of white radish combine harvester [J]. Agricultural Development and Equipment, 2021, (02): 29-32.

[10] GAADHE SK, CHAVDA SK, BANDHIYA RD, et al. Optimizing carrot harvesting machine design: incorporating soil and crop parameters [J]. International Journal of Environment and Climate Change, 2023, 13 (10): 3680-3689.