ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

A fully automatic grape harvesting robot

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Abstract: *China's grape planting range is wide, the yield is large. In the production link, the time of picking and harvesting is short, labor-intensive and the amount of labor is large. The traditional way of hand-picking cannot meet the requirements of grape industrialization and large-scale production. A new type of automatic grape harvesting robot is designed. The robot is composed of harvesting main engine and transport auxiliary unit. By visual recognition technology and near infrared spectrum detection technology to achieve accurate positioning of grapes, and judge its maturity and quality; The bionic octopus flexible mechanical arm is used to pick grapes. The flexible structure with high degree of freedom can adapt to the complex environment in the vine, wrap and hold the grape cluster in a curling way, and prevent the grape from falling. There are fruit branch scissors at the front end of the bionic octopus tentacle robot arm to realize the separation of grape bunches and grapevines; The process of grape packaging and labeling is completed in the collection host; The auxiliary transport machine is connected with the main machine, and the rotating structure is designed to exchange the empty basket with the grape basket on the main machine, so as to ensure the continuous picking of the main machine; The transport auxiliary machine will transport the packaged grapes back to the warehouse, and then it can be directly transported to the market for sale. The device has self-adaptability in structure, can adapt to different planting methods and different kinds of grapes all over the country, in line with the concept of green sustainable development, with high market value and economic benefits.*

Keywords: *grape picking, identification, positioning, flexible harvesting, packaging, classification, transportation, recycling*

1. Introduction

1.1 Research background of works

Grape is a common fruit in daily life. It can be eaten raw, dried or made in wine. Its roots and vine parts can be used for medicinal purposes. In recent years, As shown in Figure 1, China's grape production has been increasing continuously. By 2020, China's annual grape production had reached 14.31 million tons, accounting for about 19% of the world's total.

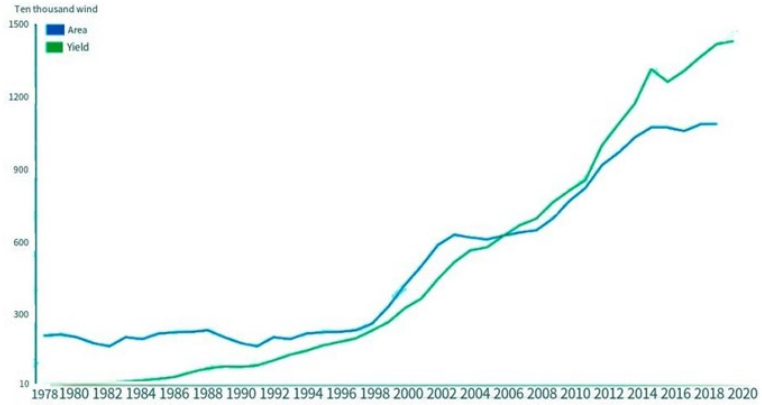

Figure 1: Grape production in China

China's grape production is large, but there are some problems such as small scale of grape growers, insufficient promotion of advanced planting technology, and lack of rationalization, systematization, standardization and mechanization management mode. China's grape planting varieties are relatively

ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

fixed, a large number of grapes are concentrated and mature every year, the picking period is short, and the manual picking work is intense and low efficiency.

As shown in Figure 2, at present, the existing grape harvesters mainly beat the grapes through mechanical vibration, and conduct the high-frequency vibration of the grape fruit, so that it is separated from the fruit stem. But there are a series of problems with this mechanical picking method:

First, the mechanical vibration will cause damage to the grapes, friction or extrusion collision is easy to make the grapes damaged, affecting the quality of the grapes picked, in addition, damaged grapes will speed up the rot of other grapes, the loss is large; Second, after mechanical vibration harvesting, there will be a large number of ears left on the grapevine, resulting in a steep increase in the subsequent manual tassel pulling workload, and can not reduce human resource consumption; 1 Third, the existing picking device operates by wheel drive, due to the large volume and heavy weight of the device, it will crush and stabilize the soil during the process, resulting in serious soil compaction, affecting the planting and production of grapes; Fourth, when the harvester works, a large number of branches and leaves will be shaken off together, leading to the weakening of the photosynthesis ability of the grapevine, which is not conducive to the sustainable growth of grapes[1-3].

Figure 2: Existing large machinery for grape picking

1.2 Significance of Works Research

In view of the above problems, there is an urgent need for a grape harvesting device that meets the requirements of automation and systematization, so as to promote the high-quality development of the grape industry, reduce the labor cost of grape production, reduce the loss in the process of grape harvesting, and increase the benefits of fruit farmers. It needs to have the following characteristics:

1) Reduce labor costs: can effectively replace manual grape picking, collection, packaging and other work, functional integration and high degree of automation.

2) Reduce the loss: reduce the unnecessary loss in the process of grape harvesting, in order to improve the recovery rate of high-quality and high-grade fruit.

3) Humanized and environmentally friendly: small space occupation, does not interfere with other farming activities, convenient collection and follow-up treatment; The picking process has little interference with the environment of the park, reduces soil compaction, and ensures soil quality. Based on the above requirements, a fully automatic grape harvesting robot is designed to replace people to realize a series of processes of grape harvesting, meet the requirements of high quality and less manpower, and has good application value and market prospects.

2. Research Content

2.1 Design scheme

Aiming at the current situation of low efficiency of traditional manual picking, simple and rough mechanical picking, and easy to hurt flesh, a grape picking device with high integration of positioning, harvesting, packaging and transportation is designed.

ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

As shown in Figure 3, the whole device is mainly composed of harvesting main engine and transport auxiliary unit, including movement module, positioning and detection module, picking module, packaging and storage module and transport module. As the grape spacing is small, the height of the vine is low, not suitable for large machinery running in the ridge, so consider the steel cable above the vine, in the two ridges between the grape light small device in a similar way to the cable car suspension, to achieve the efficient use of space; Turn and turn at the head and end of the ridge, and make reasonable planning for the operation path in the park; According to the size and color of grape fruit, use visual recognition technology to accurately locate grape clusters; The bionic octopus tentacle robot arm structure was used to harvest grapes; The harvested grapes enter the packaging module through the transmission belt, the grape type and quality are judged by near infrared detection, and the corresponding labels are put into the grape basket; After the grape basket is filled, it is docked with the transportation auxiliary machine, and the auxiliary machine receives the grape basket and passes the empty basket to the harvesting host to ensure the continuous progress of the harvesting work. Then the auxiliary machine will transport the filled grapes to the warehouse for sale or processing, and the new empty basket will be transported to the host machine to complete the transportation cycle.

Figure 3: Overall design of the device

1) Motion Module

Transport auxiliary engine The top of the device is fitted with a locking device and suspended on two steel cables parallel to each other. When working, the device moves along the steel cable. The maximum speed of the picking host is 0.5m/s when working, which is equivalent to the walking speed of people. The moving speed of the transport auxiliary can reach 5m/s, which can quickly travel between the host and the warehouse.

2) Steel cable layout design of Grape Park

A double-layer steel cable is set above the two rows of grapes, and the fixed pillar is located at the first and last two sections of a row of grapes. When the device works, it moves between the 8 adjacent two rows of grapes and can pick grapes on both sides at the same time. After picking two rows of grapes, it turns and turns to pick the next group of two rows of grapes.

As shown in Figure 4, the overall steel cable is set at a height of 2m, the spacing between the adjacent two cables is 0.5m, and the free length of each cable is 110m. It is fixed at the head and tail of a column of grapes.

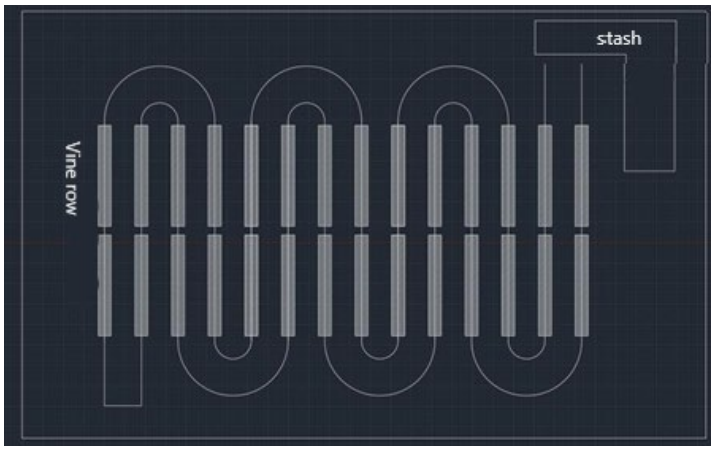

Figure 4: Steel cable layout in Grape Park

ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

3) Design of marching mode

As shown in Figure 5, in order to ensure the feasibility and stability of the robot's movement during the picking operation, a locking mechanism is designed, which can adjust the tightness between the roller and the steel cable. The mounting plate is arranged on the top of the connecting device by the silicon manganese spring steel through the fixing bolt, and the damping column wrapped by the damping spring is arranged on the top of the mounting plate. To reduce the overall shaking of the whole device caused by the reduction of mass when the main harvester transfers the full grape basket to the transport assistant; A small driving wheel is provided on both sides of the steel cable to drive the device forward; Under the joint restraint of the two steel cables, the device always keeps level when traveling, and there will be no shaking in the picking operation.

The main picking machine is equipped with 4 locking mechanisms, and the transport auxiliary machine is equipped with 2 locking mechanisms. The locking device controls the expansion of the hydraulic rod, and then controls the clamping degree of the locking block to the steel cable, which mainly has three states of loosening, fixing and braking. In addition, the locking structure can adapt to different diameters of steel cables, with a certain degree of flexibility.

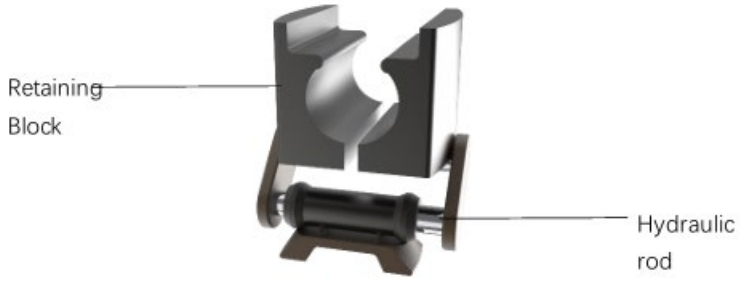

Figure 5: Structure diagram of locking mechanism

4) Positioning and detection module

The camera can be rotated 360° without dead Angle on the head, and the color, position and size of the grapes can be captured by visual recognition technology, which is convenient for the collection of the flexible manipulator after accurate positioning; The end of the bionic octopus tentacle robot arm is provided with a camera, which can realize the encircling of the grape fruit by the flexible tentacle and the accurate positioning of the shear position after the initial positioning, as shown in Figure 6.

Figure 6: Visual recognition module

5)Near infrared spectrum detection module

After collection, grapes will go through the near infrared spectrum scanning module before being put into the packaging device, and the strong penetrating ability of near infrared light will detect grapes for qualitative and quantitative analysis. On the basis of determining the composition and structure of grapes, the contents of grapevin, flavonoids, potassium, magnesium, calcium and other minerals will be further determined, so as to judge the type, maturity and quality of grapes. Convenient for packaging and labeling afterwards.

6) Picking Module

As shown in Figure 7, the bending, twisting, winding and other actions of octopus arms are completed by soft bones composed of muscle tissue. The muscle structure mainly includes transverse muscle,

ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

longitudinal muscle and oblique muscle. The thickness, expansion and torsion of octopus arms in the air are respectively, and the driving force of octopus arms mainly comes from longitudinal muscle.

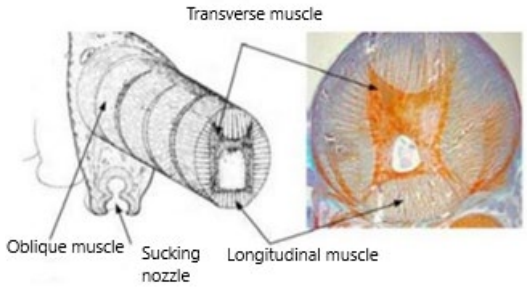

Figure 7: Cross section view of octopus tentacles

7) Bionic octopus Tentacle robotic arm

The bionic octopus tentacle robot arm is used to pick grapes, which is mainly divided into the rear mechanical arm structure and the front flexible tentacle structure. As shown in Figure 8, the rear arm structure can achieve elongation, torsion and bending, etc., to ensure that all grapes at different heights and positions can be picked;

The front flexible tentacle structure can be positioned to the grapes and wrapped around, and the scissors at the most front end will separate the grape string from the vine. The flexible design will not scratch the surface of the grapes when wrapping the grapes, and by controlling the clamping force, ensure that the grapes will not fall and will not break due to excessive squeezing.

Figure 8: Structure of the bionic octopus tentacle robotic arm

The rear robotic arm is composed of a plurality of triangular-like segments, each segment is matched along the axis by three subdivided fragments. There are three layers of ladder protruded on the surface of the segment. Each segment rotates at a certain Angle, a new matching height can be formed with the adjacent segment and the elongation length can be adjusted. When the rotation is in place, the third step of the two adjacent segments is aligned with each other, and the extension is two times compared with the initial form to realize the function of free expansion.

The flexible material of the front flexible tentacle is silicone rubber, rubber, hydrogel, etc., which has excellent flexibility and resilience and is easy to process. The bionic octopus tentacle is equipped with a sensor in the middle, which can sense the size of the force squeezing grapes in real time to avoid crushing the fruit or causing it to fall off; The front end is installed with a camera, real-time shooting in the process of tentacle movement, the application of servo continuous focus, after the identification and positioning of the whole grape for accurate positioning of the grapes, to ensure that the tentacle at the bottom 2/3 of the grape string and the fruit branch cut at the distance of the fruit stem 3~5cm to separate the grapes from the vine.

8) Packaging and sealing module

As shown in Figure 9, the grapes after picking are transported to the packaging and sealing module through the conveyor belt, and the spring buffer device is used to reduce the impact force when the grapes slip from the conveyor belt. The near infrared detection technology is used to judge the quality of the grape string, and the automatic packaging technology is used to wrap the grape string with plastic wrap and bagging. After the packaging is completed, the grape label quality is classified.

ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

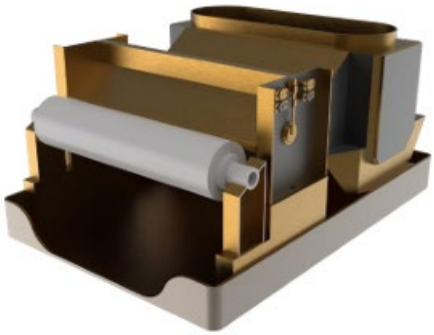

Figure 9: Packaging and sealing module

9) Structure and working principle of transport auxiliary machine

In order to realize continuous and efficient harvesting process and solve the difficult problem of changing baskets in the air, the transport auxiliary machine is designed to cooperate with the main harvester, which mainly plays the role of changing baskets and transporting, and realizes the function of automatic recovery.

The auxiliary transport machine mainly adopts a rotating structure similar to the Ferris wheel. As shown in Figure 10, the device is mainly composed of a central rotating shaft, a support and a basket frame. The support is linked with the center rotating shaft and can be rotated around the center rotating shaft;

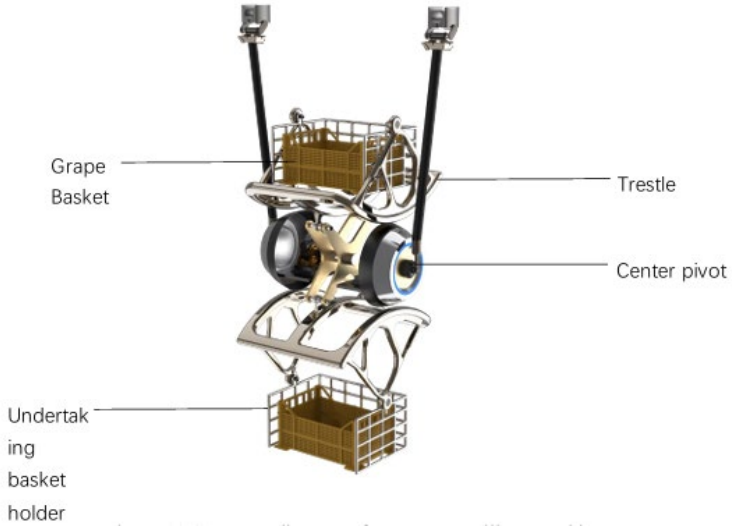

Figure 10: Structure diagram of transport auxiliary machine

10) Grape basket exchange process of main and secondary machines

The grapes are sent to the end of the harvester after the package is completed, and fall into the grape basket. When the grape basket is full, the fork carrying the grape basket is pushed out laterally and sent to the top of the auxiliary machine to undertake the basket frame. Then the fork of the main machine moves vertically down, staggered and separated from the undertaking basket frame of the auxiliary machine, and the grape basket falls to the undertaking basket frame to achieve the transmission process, as shown in Figure 11.

At this time, there are two grape baskets inside the transport auxiliary machine, the top is full, and the bottom is empty. Through the same principle, the empty grape basket is rotated to the position of the original full grape basket on the top, and then the fork of the harvesting host machine moves from the bottom up to take over the empty grape basket and continue to harvest grapes; After passing the empty grape basket to the harvester, the transport auxiliary machine carries the full grape basket to the warehouse. After the people take down the grape basket and replace the empty grape basket, the transport auxiliary machine returns to the main engine to stand by and prepare for the next stage of the work

ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

cycle[4-5].

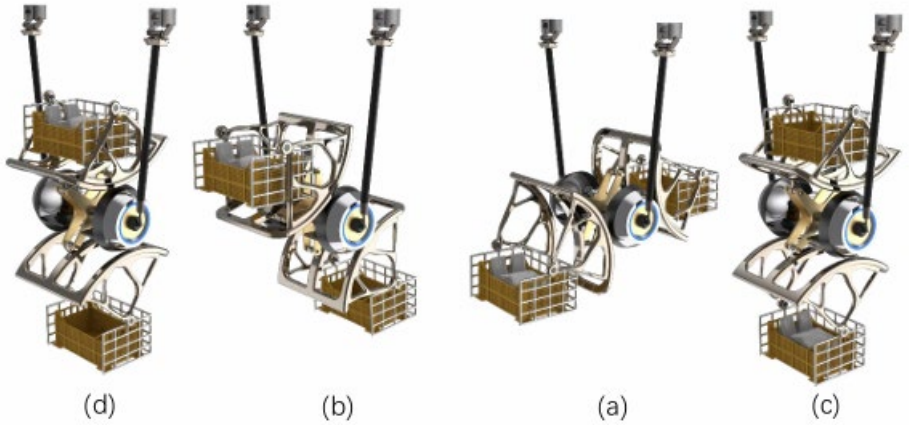

Figure 11: Flow chart of grape basket exchange of the auxiliary transport machine

2.2 Feasibility analysis

1)Analysis of steel cable placement in the garden

The double steel cable is located above the grapevine, the height is about 2m from the ground, the direction is parallel to the grape ridge, the horizontal length is about 110m, and the fixed rod is set at the end of the grape ridge, which plays a fixed role in the steel cable. Since the steel cable is set above the vine and does not occupy land space, the road surface of the grape park basically maintains the existing condition when the device is not working, and the daily management of farmer households such as deinsectization and fertilization, core picking and ear pulling is not affected, and can be carried out in the road of the park and between the grape ridges.

2) Overall design and analysis of the device

The whole device is fixed by the main harvester through the telescopic connecting rod and the steel cable. When working, the device is hung on the steel cable, firmly fixed on the track through the locking structure, and runs on the parallel track. The main engine shell is a streamlined structure, compact package of the internal parts of the device structure, in the two vertical rod fixed steady forward, not easy to shake. The bionic flexible mechanical arm has light weight, high degree of freedom, and will not break due to bump during the picking process, and can enter between vines to pick grapes. The docking part of the harvester and the transport auxiliary machine can reach the same height by lifting and rotating, and the grape basket can be transferred smoothly. In the design process, the unnecessary structure design is avoided, such as the transport auxiliary machine without bulky shell, and the movement on the steel cable abandons the cross bar, pantograph and other fixed ways, and tries to achieve the target function with the lightest weight and simplicity.

3) Steel cable bearing analysis

The steel cable used is composed of multiple strands of steel rope, the diameter is 2cm, the length is equal to the length of the ridge, about 100m, the weight per meter is about 3.8kg, the strength is 2020MPa, the nominal tensile strength is 1770MPa. The total mass of the whole harvesting device is 50kg, and a basket of grapes weighs about 30kg. In the actual cable car cable work, the diameter of 5cm steel cable can support 500kg cable car, in this device designed with a diameter of 2cm steel cable can meet the load of grapes when the device.

In the actual operation, the downward convex deformation will occur due to the downward pulling force. When the picking device runs to the middle position of the single ridge, the convex deformation is the largest, and the maximum deformation is about 0.05m. At this time, the distance between the lower steel cable and the top of the grapevine is about 0.2m, and the camera at the bottom of the picking device can still cover the whole target object under this distance, identify and capture the grape string, and the operation is normal.

4) Shape and size design

The housing of the harvester main device adopts a streamlined design, with a length of 1.5m, a

ISSN 2616-5767 Vol.7, Issue 4: 170-178, DOI: 10.25236/AJETS.2024.070424

maximum width of 0.8m, a minimum width of 0.72m, a height of 0.7m, and a lengthed-width ratio close to the golden ratio. There is an opening at the top of the front end of the shell to place the grapes after picking, and the beginning is a rectangle of 0.2m in length and width. The distance from the height of the conveyor belt below is 0.3m, and there is enough space to adapt to different sizes of grapes. The bionic octopus manipulator is composed of two sections, the total length of 0.8m in the natural state, of which the back end can be twisted and extended, the maximum elongation is 0.5m, the diameter is 0.1m, and the working time can be extended and rotated along the axial direction, and can also be bent; The front end is a large flexibility structure with a length of 0.3m and a diameter of 0.05m. The grapes are wrapped by bending. The end of the bionic tentacle is equipped with fruit branches. There is a grape conveyor belt inside the main machine, and the concave and convex structure is designed to transport grapes more effectively. Under the horizontal conveyor belt is the device control module, storing the device operation program and grape data. The end of the conveyor belt is connected with the packaging device, which is 0.7m long, 0.6m wide and 0.5m high. The lifting fork for docking with the transport auxiliary machine is installed on the outer side of the shell tail, which can lift the grape basket up and down 0.3m for docking with the transport auxiliary machine.

In the rotating structure of the transport auxiliary machine, the diameter of the circle where the grape basket is rotated is 1m, the size of the grape basket is 0.4m in length, 0.3m in width and 0.3m in height. The shell of the central rotating power shaft module is similar to two hemispheres with 0.3m in diameter and a drive motor is built in.

The design of the main engine and the auxiliary machine effectively solves the difficult problem of air harvesting and basket changing, which not only improves the overall working efficiency of the device, but also greatly saves manpower, and has great market benefits[6-7].

3. Domestic and foreign research status and development trends

The starting point of the design of this device is the existing problems of manual and mechanical picking, and the structural work is carried out by the actual demand I can design it. The grapes were harvested taking into account the ripeness, weight and the possibility of grape drops during the harvest. Therefore, it has good application value and market prospects.

4. Conclusions

The device is large in volume and heavy in weight, which will crush and stabilize the soil during the process, resulting in strict soil compaction, affecting the planting and production of grapes, and carrying out application innovation.

The steel cable is set above the grapevine, and the two rows of grapes on the left and right side of the device can be picked at the same time. When the picking operation is not carried out, only the steel cable above the grapevine is retained in the grape garden, which does not occupy a vacant space, which has little impact on the environment of the garden, and at the same time, the damage to the soil of the orchard by the large volume and weight device is avoided.

In order to solve the problem of slow picking efficiency, the overall structural innovation was carried out.The device is divided into two parts: main machine harvesting and auxiliary machine transportation to improve the overall work efficiency. A rotating mechanism is designed to realize the exchange process between the picking machine and the grape basket of the transport machine. The two devices are coordinated in front and back, and after each exchange, the basket filled with grapes is at the bottom, and the transportation process device is stable.

Acknowledgement

2023 National innovation and entrepreneurship training program for college students (Project Number: S202310497133).

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