International Journal of Frontiers in Engineering Technology
ISSN 2706-655X Vol.6, Issue 3: 184-190, DOI: 10.25236/IJFET.2024.060324

# Multi-terrain Navel Orange Harvesting Machinery Based on Self-balancing System

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***Abstract:*** *In order to solve the problems of complex planting terrain and low efficiency of manual picking, in order to respond to the construction requirements of "rural revitalization" and "agricultural poverty alleviation" in China, an all-terrain bionic navel orange picking machine was designed in this project. This product contains a double bionic flexible fruit picking structure and a multi-terrain self-balancing adaptive motion structure, which has the advantages of high transportation capacity, high picking efficiency, high terrain adaptability and high cost performance, realizes the automatic picking of navel oranges, can effectively improve the picking efficiency of navel oranges, and help the development of the navel orange picking industry.*

***Keywords:*** *Navel orange picking, Bionic flexibility, Self-balancing, Multi-terrain*

## 1. Introduction

Navel orange is a cultivar of citrus, belonging to the citrus subfamily, the peel is rougher, the top of the fruit has an umbilicus, the fruit shape is larger, it has the effect of decomposing fat, clearing fire and nourishing the skin, etc., and is deeply loved by people.

Due to the limitation of the growth conditions of navel oranges, their high-quality varieties are mainly distributed in mountainous areas and terraced fields. Therefore, the balance conditions and obstacle crossing performance conditions of mechanical equipment are required to be high, and the degree of mechanization of navel orange picking in China is still at a very low level. In the harvest and picking season of navel oranges, it is all picked by manpower, and the basket is carried over the mountain, and the picking efficiency is low. According to statistics, a navel orange grower's picking labor expenses generally account for more than 20% of the output value, in the harvest season, the average daily wage of a single person is as high as 400 yuan, and face the difficulty of finding work, and now, the large input of labor in the harvest link has become a heavy burden on the development of navel orange farmers.

At present, the field of navel orange harvesting machinery in China is still relatively blank, from the international point of view, there are also many problems in the application of mechanized fruit picking device in navel orange picking at present: although the navel orange picking device that collects by shaking branches is very efficient, but the volume is larger, only suitable for plain operation, can not adapt to the topographical conditions of many navel orange planting areas in China;

In summary, a navel orange picking machine with good terrain adaptability, high picking efficiency, high degree of automation, large carrying capacity, low device cost and low operating cost can better solve the problems existing in the process of today's navel orange picking, and also has high economic value and good promotion prospects.

## 2. Research Contents

### *2.1. Overall Scheme Design*

Figure 1 shows overall installation and installation positions of each structure. The frame module is located at the bottom of the device, with drive, shock absorption and bearing functions, and is designed for common terrain of navel orange plantations such as terraces, slopes and flat land, with strong obstacle crossing ability, running speed and bearing capacity.

The self-balancing system module is located between the chassis module and the fruit storage box, which is used to keep the fruit storage box and each module on it stable, so as to provide a good working

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environment for it and ensure the efficient picking work.

The harvesting module is located above the fruit storage bin and features a rotatable base, three spherical articulated robotic arms, and a bionic frog-snake adaptive picking mechanism. The picking module has high flexibility, large picking range, and the adaptive picking mechanism is designed for navel oranges and similar fruits, with simple picking process, high picking efficiency and good picking effect.

The recovery pipeline and storage bin module are also one of the means to improve the picking efficiency of this device. The side of each spherical joint manipulator arm is equipped with a pipe fixing ring, with the temporary storage box at the bottom and the main and auxiliary pipelines, forming a high-speed recovery channel from the picking mechanism to the fruit storage box, due to the special material selection and design, the whole process can be realized only by gravity, and after many times of deceleration in various parts of the path, the navel orange skin will be well protected.

The electronic control module coordinates the work of the various modules and relies on the sensors installed everywhere to obtain a large amount of information, such as inclination sensors, pressure sensors, cameras, etc. Based on the obtained information, the control system will control the movement of the motors in various places, complete the rotation of the robotic arm, the positioning of the picking mechanism, the action of picking and disengaging from the branches, and the movement of the self-balancing system. Therefore, this device has a strong perception of the external environment, and can quickly make judgments based on external environmental information to ensure its own environmental adaptability, so as to improve the speed and stability of picking.

*Figure 1: Overall schematic view of the installation*

### *2.2. Frame Module*

Figure 2 shows framework installation principle. The frame of this device mainly contains: tires, shock absorbers, engines, batteries, axles, universal joints, differentials, etc., the main material of the frame is high-strength steel plate, the axle is made of 40Cr and other types of steel, and the shock absorbing spring is made of 65Mn.

This device is four-wheel drive, the fuel tank is front-mounted, and the engine is rear-mounted to maintain balance. The fuel tank is well fixed, a protective cover is installed on the outside, and the battery is also installed in the protective case. In order to achieve better terrain adaptability, the frame module adopts wide tires and is equipped with shock absorbing springs, which are modeled after existing off-road vehicles to achieve better shock absorption.

The chassis of the device is a high-strength steel structure, with good bearing performance, with the chassis guard plate made of hard plastic, can better protect the internal structures, and the material price is low; the device tires are larger, the chassis is higher from the ground, can reduce the influence of terrain undulations on the car body. In the face of the rough road in which the device is located, the above design can lay a solid foundation for its good passability.

ISSN 2706-655X Vol.6, Issue 3: 184-190, DOI: 10.25236/IJFET.2024.060324

*Figure 2: Schematic diagram of the installation frame*

### *2.3. Self-balancing System Module*

Figure 3 shows fruit storage box and self-balancing module. The self-balancing system is mounted above the frame and under the fruit storage bin, and has a spindle and four electrically retractable support rods fixed to both sides of the frame. The main bearing carries a large weight, made of medium carbon steel, and carries most of the weight of the fruit storage box and navel oranges, the picking mechanism module and the recovery pipeline module. The electric telescopic support rods on both sides can adopt the existing finished product device, and considering that the upper weight can reach 600kg when fully loaded, the thrust of each electric telescopic support rod needs to reach 60kg when running slowly.

The inclination sensor horizontally mounted on the frame transmits back the inclination angle value of the car body at the current moment to the main control board once per second, if the difference between the two values exceeds the threshold, the comprehensive information judges whether the current inclination is sudden or long-term, and if it is the required inclination for a long time, the main control board transmits the angle that needs to be adjusted to the motor drive. The spindle is driven by a stepper motor mounted on the frame, which can receive the electrical pulse signal from the drive and convert it into the corresponding angular displacement. The electric telescopic support rods on both sides move with the rotation of the fruit storage box and play an auxiliary supporting role. The two work together to achieve the smooth rotation of the fruit storage box and the picking module.

*Figure 3: Fruit storage box and self-balancing module*

### *2.4. Picking Module*

#### *2.4.1. Robotic Arm*

Figure 4 shows the robotic arm of the picking module. The bottom of the picking module is a trough chassis, one end of which is equipped with a turntable for the installation of the robotic arm and the

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picking mechanism, and the other end for the installation of the fruit temporary storage box.

The trough chassis is three identical spherical joint manipulators, and the joint connection is a sphere, which is driven by a motor installed below the spherical joint, which is the same as the existing spherical joint, and the function is similar to the human ball joint, such as: shoulder joint, ankle joint, hip joint, etc., compared with the rotary joint, it has higher flexibility and range of motion, and can better adapt to the complex navel orange canopy environment. The skeleton of the robotic arm is made of aluminum alloy (silicon-aluminum alloy) as the material, which makes the picking module lightweight as a whole, thereby reducing the burden on the motors of each joint and further reducing the overall weight of the device.

The two sides of the skeleton of the robotic arm are equipped with openable and closing-like guards similar to snake scales, which are closed during picking to prevent tree branches from being entangled in the inside of the robotic arm, and can also be used for waterproofing in rainy days. The skeleton of the robotic arm is also equipped with a pipe fixing ring, and a pipe can be fixed between each two fixing rings.

*Figure 4: Schematic diagram of the robotic arm*

### *2.4.2. Manipulator*

Figure 5 shows the picking mechanism of the picking module. The top of the picking module is equipped with frog-like and snake-type adaptive picking mechanisms. The picking mechanism comprises a retractable adsorption rod, an air pump, an upper joint finger, a lower joint finger, a drive module, an identification and positioning module, a moving fixed block, a clamping slide rail hanging plate, a flexible clamping cushion block, a spring guide pillar, a hinge and the like. There is a hinge between the finger joints to form a rotating pair, and the two are connected by a spring guide pillar, and the fingers and the driving module form a connecting rod mechanism, and the detachable design of the finger joints can be realized through the chute mechanism.

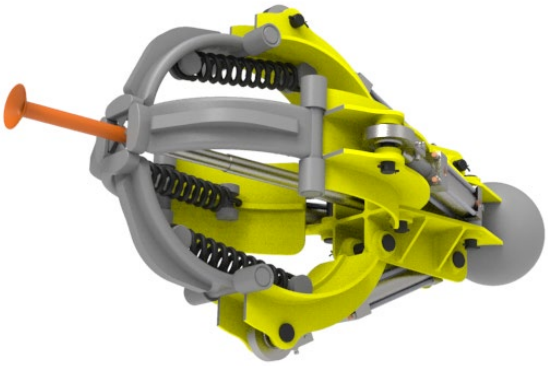

*Figure 5: Schematic diagram of the picking mechanism*

When the knuckles are closed, the push rod is retracted to drive the joints under the fingers to close, the joints under the fingers drive the joints on the fingers to contract inward, the joints on the fingers touch the upper surface of the navel orange and are pushed by the navel orange, the spring guide pillar is

ISSN 2706-655X Vol.6, Issue 3: 184-190, DOI: 10.25236/IJFET.2024.060324

stretched at this moment, and a traction force is provided to the joints on the fingers, and the two forces cancel each other out by selecting the elastic coefficient of the spring, so that the effect of flexible grasping on the surface of the adaptive navel orange is realized, and it has the characteristics of simple and reliable control and stable grasping.

The shear structure of the end effector designed at the second knuckle of the manipulator is designed as a bionic serpentine occlusal structure, which effectively expands the occlusal area of the cutting mechanism for the fruit stalks of navel oranges with different growth directions[1-3].

#### *2.4.3. Picking Workflow*

When working, the retractable adsorption rod is extended, similar to frog tongue predation, under the guidance of the camera to determine the position of the navel orange, the air pump starts to generate negative pressure and complete the adsorption, complete the positioning work, and then the adsorption rod pulls back the navel orange. After pulling back a certain distance, the first and second knuckles of the picking mechanism are buckled inwards to cover the navel orange skin. The adsorption rod is further pulled back to a suitable place under the guidance of the end effector shearing mechanism, where the second knuckle of the picking mechanism almost completely covers the navel orange, and a certain margin is left for shearing to complete the picking work. Considering that the surface of the navel orange is rougher, the selected air pump has a large power and is installed inside the bottom section of the robotic arm, which can realize the close attachment of the navel orange peel.

The picking mechanism completes the positioning of the navel orange and the detachment from the branches through the predation of the bionic frog, tightly wraps the skin of the navel orange through the second knuckle of the bionic snake to ensure that the cutting position is close to the navel orange, and completes the cutting of the fruit stalk in all directions through the bionic snake end effector to complete the picking action.

### *2.5. Recycling Pipes and Fruit Storage Bin Modules*

The recovery pipeline is composed of a pipe fixing ring on the skeleton of each section of the robotic arm, a fixed temporary storage box on the chassis of the picking module, a main and auxiliary recovery pipeline, a rotatable sprinkler, a flexible pipe and a buffer layer. Figure 6 shows the retaining ring of the recovery pipe. Figure 7 shows the recycling pipeline.

The picking mechanism is connected with the first fixing ring, between every two pipe fixing rings, between the bottommost third fixing ring and the temporary storage box, the pipe is made of plastic, and the internal navel orange contact surface is coated with a coating material that reduces friction - solvent-based two-component thermosetting modified polyurethane. Due to the excellent bending ability of the pipeline, each section of the pipe can adapt to the relative position of the front and rear mechanisms without sagging, so that the navel orange can be recovered only by gravity.

*Figure 6: Schematic diagram of the retaining ring of the recovery pipe*

An opening and closing mechanism is installed inside the temporary storage box, which communicates with the microprocessor released by the temporary storage box at all times, and the microprocessor judges whether there is fruit in the temporary storage box and the temporary storage quantity through the pressure on the wall of the temporary storage box, and under the coordination of the

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microprocessor, the four temporary storage boxes release navel oranges intermittently to ensure the orderliness of the whole recovery process.

After the temporary storage box is released, the navel orange enters the secondary recovery pipeline, and after being decelerated by the buffer layer with high friction coefficient material attached inside, it enters the main recovery pipeline, and is stored in various places of the fruit storage box under the guidance of the rotatable nozzle, so as to ensure the integrity of the navel orange peel and the space utilization rate of the fruit storage box, as shown in Figure 7.

*Figure 7: Schematic diagram of the recycling pipeline*

### *2.6. Electronic Control Module*

The electronic control module includes a main control board, a variety of drivers, a variety of sensors, a variety of cameras, a variety of secondary microprocessors and other components.

Each sensor collects information such as frame inclination, temporary box wall pressure, temperature and humidity in real time, and transmits the information to each microprocessor for data analysis, and the microprocessor sends instructions to the drive to make the motors start working.

The main control board coordinates the work of all parts and can also accept external instructions to further coordinate the entire workflow.

The cameras consist of high-precision, high-degree of freedom cameras mounted on the front and rear of the frame and navel orange recognition cameras mounted at the picking mechanism. The cameras in the front and rear of the frame are responsible for observing the external environment, assisting in obstacle avoidance and determining the picking target, while the navel orange recognition camera is responsible for transmitting the image back to the navel orange recognition microprocessor, which is used to determine the specific position of the navel orange and guide the adsorption rod to complete the positioning[4-5].

## 3. Conclusions

The innovation points of this device mainly include three aspects: structural innovation, combination innovation and functional innovation. In terms of structural innovation, this device is designed with a bionic frog-like predation and snake-shaped cutting fruit picking mechanism, which can efficiently locate navel oranges and cut fruit stalks close to the skin, with fast picking speed and protective effect on the skin of navel oranges. In terms of combination innovation, this device combines the off-road chassis with the picking self-balancing system, which has better terrain adaptability for the common terrain of navel orange plantations such as terraces, flat land, and slopes, and ensures that the working environment of the fruit storage box and picking module is stable and good. In terms of functional innovation, the device is designed with a fast recovery channel for navel oranges, equipped with a retarding device and a rotatable nozzle, which improves the efficiency of navel orange picking and the utilization rate of fruit storage box space.

At the same time, this device also has a broad application prospect. The self-balancing system in the device can be extended to intelligent robots moving in complex terrain, such as mountains and slopes, to

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ensure the stability of their working platforms. The Bionic Snake Adaptive Shearing Knife can be extended to the mechanical cutting design of vegetables and fruits, such as tomatoes, persimmons, etc., which also have intricate growth orientations and pay attention to the quality of the skin. The bionic frog picking mechanism can be extended to the picking of a variety of fruits, which can speed up its positioning and picking speed. The fast recovery pathway in the device can be extended to other fruit recovery processes, allowing for orderly recovery of fruit and preservation of the peel by gravity alone.

**Acknowledgements**

This work was financially supported by National innovation and entrepreneurship training program for college students.

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