Proceedings of 2021 IEEE
International Conference on Mechatronics and Automation
August 8 - 11, Takamatsu, Japan

Design of Automatic Picking Robot Based on 2-DOF Stabilized Platform

Chao Zhang, Bing Zhang
Innovation Center Of Robotics And Intelligent Equipment
Dongguan University Of Technology
Songshanhu Scientific Industrial Park, Dongguan, Guangdong Province, China
E-mail: zc.ch@qq.com

Hao Zhang
Department of mechanical and electrical enginee
Guangdong University Of Technology
Guangzhou Higher Education Mega Center, Panyu District, Guangzhou, Guangdong Province, China
E-mail: 1037904271@qq.com

***Abstract* - Farmland automatic picking robot with large span operation ability in the vertical and horizontal direction has a wide application prospect. It can be used to pick bananas, boro honey, grapefruit, etc. In this paper, an automatic picking robot based on 2-DOF stabilized platform is designed for the banana picking. There are three main components of the picking robot including the moving chassis which can adapt to the complex ground environment in the field, a 3-DOF mechanical arm and a grip-shear integrated operation handle at the end of the manipulator arm. A 2-DOF stabilization platform is designed to compensate the rolling and pitching caused by the soft soil and the posture change of the manipulator arm.**

Index Terms - Picking robot, Stabilized platform, Grip-shear integrated operation handle.

I. INTRODUCTION

Fruit picking is seasonal and time intensive, which needs a large amount of labor. Due to the social and economic transformation and development, the aging of the agricultural working population is becoming more and more serious. The automation of fruit picking is a preferable way for sustainable agricultural development[1]. Farmland automatic picking robot with large span operation ability in the vertical and horizontal direction has a wide application prospect. It can be used to pick bananas, boro honey, grapefruit, etc. Take the bananas for example, they are always picked at high altitude which leads to low efficiency and damage. Agricultural robot research began in the 1980s in Japan, Europe, the United States and other developed countries [2]. In 1985, the Department of Agriculture of Australia designed a banana picking machine[3]. The banana picking machine consists of a miniature farm tractor trailer, a hydraulically driven mechanical arm, a cutting mechanism and a container at the end of the manipulator. In recent years, some representative research results have emerged. Hainan University proposed a guideway mobile banana picking machine, and designed the moving device, clamping device and cutting device[4]. An all-directional pneumatic fruit picking machine was designed in Hubei University of Arts and Science[5]. The picking machine includes a clamping device driven by a hydraulic cylinder and a cutting part driven by a hydraulic motor. Shanghai Maritime University has designed a banana picking prototype machine with low manufacturing cost[6]. Fujian Agriculture and Forestry University made an in-depth study on the walking device of the banana picking machine to realize fast movement and flexible turning[7].

At present, the research on the banana picking robot is still in the initial stage, and most of the basic researches stay in the theoretical analysis and the performance test. The purpose of this paper is to design a banana picking robot based on 2-DOF stabilized platform which could compensate the rolling and pitching caused by the soft soil and the posture change of the manipulator arm. Thus it can better complete the picking task and improve the movement control precision of the picking operation.

II. PICKING OPERATION ANALYSIS AND FUNCTIONAL INDEX DESIGN

The structure and working mode of the banana picking robot are determined by the banana plant characteristics, planting environment, picking methods and other factors. First of all, we need to formulate the structure type of banana picking robot by analyzing the working environment of banana plantation. The characteristic of banana skewers is that they are arranged in rows on top of the banana pseudosperm. When picking bananas, banana farmers traditionally cut off the pseudosperm and then carry the whole bunch of bananas to the place where they are to be transported.

The spacing between banana trees in the plantation is evenly spaced in rows, generally between 2.5 and 3.5 meters. Depending on the type of banana tree, the height of the pseudosperm to the ground is about 1.5-3 meters. In addition, the road between the rows of banana trees is frequently obstructed by potholes and ditches. So the transport platform of banana picking robot should be able to get over barriers or ditches.

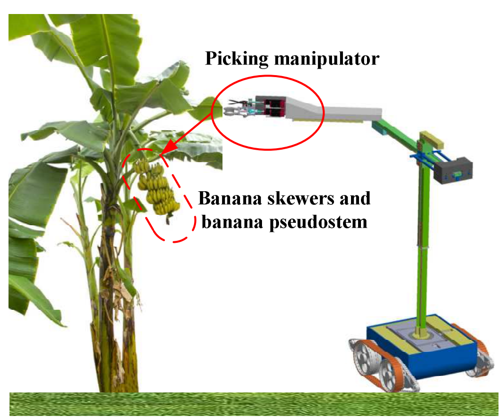


Fig. 1 Banana picking robot and the picking operation schematic by a picking manipulator

2021 IEEE International Conference on Mechatronics and Automation (ICMA) | 978-1-6654-4101-8/21/$31.00 ©2021 IEEE | DOI: 10.1109/ICMA52036.2021.9512645

The banana picking robot and the picking operation schematic by a picking manipulator is shown in Fig.1. For the design of the picking manipulator at the end of the picking arm, the banana pseudosperm is first grasped and then cut off. After the cutting action is completed, the banana skewers would be placed into the temporary storage container on the ground behind the picking robot through the manipulator arm movement. In the process, the clamping state is maintained.

The weight of the banana skewers is regularly between 30 kg to 80 kg. So the load of the picking arm and the holding force of the gripping hand are required to meet the requirements. In addition, under the limit posture condition when the picking arm holds banana skewers, the robot should be prevented from rolling from the view of overall design point.

The robot moves between banana rows and picking operation cycle are shown in Fig.2. For the action description of the robot in the picking operation cycle, the first step is to change the direction of the banana picking robot. The banana picking robot rotates at a certain angle to make sure that the robot is directed at the banana tree trunk that needs to be picked. The second step is to control the expansion and rotation of the robotic arm to make the picking manipulator in an appropriate position for the Clamping and shearing operations.

Fig.2 Robot moving between banana rows and the picking operation cycle

When picking, the gripper on the picking manipulator first grabs the banana pseudosperm, and then a cutting knife up on the gripper cuts off the pseudosperm. When the cutting operation is done, the arm contracts and rotates to place the banana skewers in a storage car that runs immediately behind the robot.

For the picking operation cycle planning scheme, the No.1 banana tree on the left side of the robot is firstly picking as shown in Fig.2. Then the robot turns right to pick the No.2 banana tree at the corresponding position on the right side. Finally, move the robot along the middle path of the banana tree, and turn to the left row to start picking the No.3 banana tree.

To sum up, the banana picking robot designed in this paper requires its structure to be more flexible and portable. It can be more convenient to adjust the height of the vertical direction and the width of the horizontal direction. And the ability to prevent overturning in the process of picking is also needed to be taken seriously. The overall design index of the banana picking robot is shown in Table 1.

TABLE I
OVERALL DESIGN INDEX OF THE BANANA PICKING ROBOT

Parameter	Numerical value
Robot ground motion speed	1.5m/s
Minimum turning radius	0
Maximum ability to cross the gully	0.5m
Maximum climbing ability	20°
Maximum clamping weight	30-80 Kg
Adjusting range in the vertical direction of the picking manipulator from the ground	0.3~3 m
Maximum lateral extension distance of the manipulator arm (relative to the center position of the robot)	2 m

III. OVERALL STRUCTURE DESIGN

The banana picking robot works on the farm floor. It has to face a complex road operating environment, such as uneven ground and irrigation ditches between banana rows. Meanwhile, the large span task in the vertical direction and the horizontal direction should be met. The end load of the manipulator is also relatively large, reaching about 80kg. Preventing the robot from rolling is also an important factor to consider. A two-degree-of-freedom stable platform will be used in the design of this paper. On the whole, the overall design of the robot faces some typical challenges.

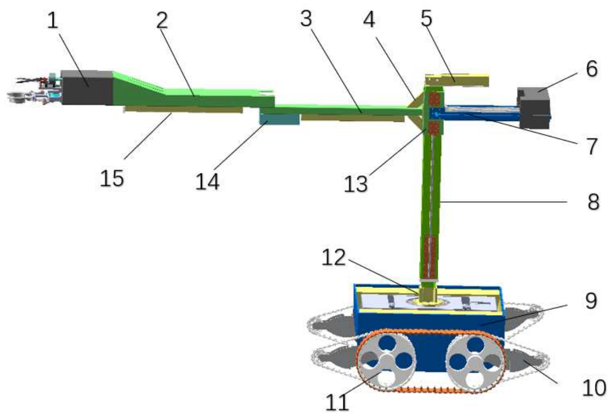
A. General Structure Description

Banana picking robot generally includes three parts: the robot moving chassis which can adapt to the complex ground environment in the field, a mechanical arm with large span operation ability in the vertical direction and the horizontal direction and a grip-shear integrated operation handle at the end of the manipulator arm.

For the stable operation of the manipulator arm, the uncertainty in the posture change of the robot moving chassis on the soft soil in the field and the large load at the end of the manipulator arm may cause excessive lateral torque. Therefore, a 2-DOF stable platform is designed between the moving chassis and the manipulator arm.

Stabilizing platform has a wide application range to compensate for the shaking of vehicles, ships and aircraft during movement. In this paper, a two-degree-of-freedom stable platform is designed to compensate the rolling and pitching caused by the soft soil and the robot arm posture change. The stable platform could also reduce the influence of the shaking caused by the clamping and shearing of the picking manipulator. It is necessary to analyze the actual needs of the stabilizing platform and design the overall scheme of the stabilizing platform, which mainly includes two parts: the mechanical structure scheme and the effective driving of the lateral torque caused by the manipulator arm and the effective load.

In this paper, the manipulator arm adopts the cylindrical coordinate robot principle to design the mechanism. It does not adopt the traditional RPP structure of cylindrical coordinate robot, but modifies the transverse bar and uses the RPR structure. The RPR structure can avoid the phenomenon of additional torque caused by the large gravity on the rotary joint of the transverse rods when the picking manipulator grabs the banana skewers .



1- The grip-shear integrated operation handle at the end of the arm; 2- Second-stage transverse link; 3- First-stage transverse link; 4- Transversely stiffened plate; 5- Two stage synchronous telescopic drive device in the vertical direction; 6- Gravity balancing counterweight 7- Gravity balancing drive module; 8- First-stage telescopic link; 9-Robot moving chassis; 10- Actively driven swing arm; 11- The driving wheel of the main track; 12-The 2-DOF stable platform; 13- Second--stage telescopic link; 14- Transverse rod rotating power unit; 15- Transversely stiffened plate on the second-stage transverse link;

Fig.3 3D view of the banana picking robot

As shown in Fig.3, the manipulator arm structural design is mainly divided into three parts. The vertical telescopic rod adopts a 2-stage telescopic structure, but the two-stage telescopic rod is driven synchronously by the same motor. It comprises a vertical support rod, the first-stage telescopic link, the second-stage telescopic link, the synchronous telescopic drive device in the vertical direction and the pulley and slide package assembly.

The transverse movement structure of the manipulator arm includes two horizontal connecting links in series and a horizontal balancing device structure. The transverse displacement of the end of the manipulator arm is controlled by a motor driven between the first-stage transverse link and the second -stage transverse link. With respect to the other side of the first-stage transverse link, it is necessary to design a gravity balancing mechanism to increase the counterweight to prevent the whole roll of the robot when the arm is fully extended in the lateral direction and under the condition of large load. The gravity balancing mechanism is composed by the power device and the counterweight block.

B. *The moving chassis design*

Robot chassis usually requires strong maneuverability and adaptability to environmental conditions. In practical applications, tracked robots have fully demonstrated excellent adaptability to complex environments, as well as the ability to resist obstacles and cross ravines.

Tracked robot is more suitable for working in soft earth floor. There are three types of tracked chassis structure: double crawler robot, four crawler robot with 2 forward swing arms, and six crawler robot with 4 front/back swing arms.

For the banana-picking robot, considering the need for forward and backward movement, large lateral span of the manipulator arm as well as the anti-overturning requirement under the condition of large load, this paper selects a 6-track robot configuration with 4 front/back swing arms, as shown in Fig. 4. For the moving chassis design in this paper, the main track driving wheel spacing is 600mm in the front and back direction, and 1200mm in the left and right direction. The swing arm length is 450mm, so it can be calculated that the rectangular envelope area of the maximum ground support point of the robot moving chassis is 1500mm*1200mm. So it could meet the design requirement of the maximum ability to cross the gully which index is 0.5m. In addition, the angle between the swing arm track and the ground in the balance position is 18°. The swing angle design of the swing arm is ±30°. As a result, the maximum angle between the swing arm track and the ground would reach about 48°, which is easy to climb over rough surfaces.

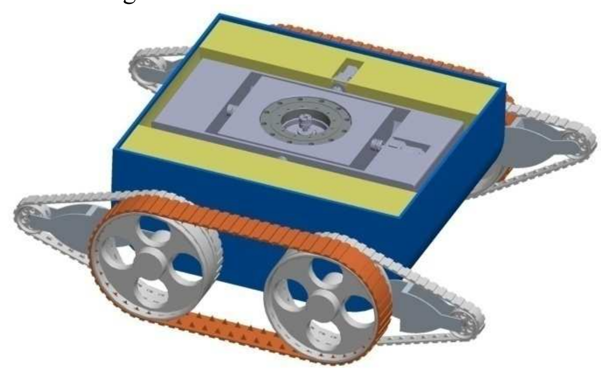
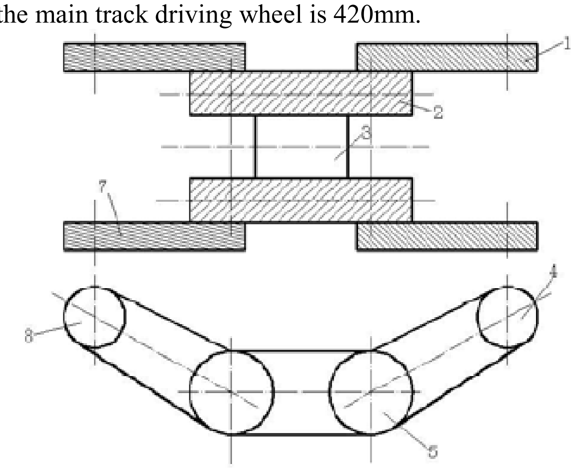


Fig.4 The 6-track robot configuration with 4 front/back swing arms

The overall track drive structure of the 4 robot swing arm is shown in Fig. 5. In the design of the drive scheme, the main track on the same side and the two swing arm tracks on the same side are driven synchronously by the same motor. The motor speed is decelerated by the planetary reducer and transmitted to the three tracks on the same side. The diameter of the main track driving wheel is 420mm.



1- Front swing arm track; 2- The main crawler; 3- noumenon of the robot moving chassis 4- Front swing arm support wheel; 5- The driving wheel of the main track; 7-Back swing arm track; 8- Back swing arm support wheel

Fig.5 Layout diagram of the 6 track on the robot moving chassis

The main tracks on both sides are driven by independent motors, which can realize 360° rotation at the origin point. The self body weight of the banana picking robot is about 596kg, and the load index is 80kg. According to the data in Table 1, such as the maximum climbing capacity of 20°, the ground speed of 1.5m/s and other parameters, we could approximately estimate the maximum driving torque and power of single-side crawler. It should be noted that climbing 20° under the maximum load condition is the limit state of the robot chassis design index. In the limit state, the driving torque of the main track on one side of the robot is 244Nm and the speed is 60r/min.

Two 600W brushless DC motor (APM-SC06A, LS Mecapion Co. Ltd.) and matched bipolar planetary gear reducer with deceleration ratio I =50 were finally selected. The rated output torque is 95.5Nm, and the peak torque T_{max} is 286.5Nm, which meets the ultimate load of the robot moving chassis and the driving torque requirements under climbing conditions. In addition, the rated output speed of the robot's main track driving wheel is 60r/min, and the corresponding ground motion speed is 1.5m/s, which also meets the design requirements.

The 4 swing arms need to be driven independently. Considering that under the condition of the maximum lateral extension of the manipulator arm and the maximum load, the end of the swing arm needs to form a ground support to resist the overall roll of the robot. So the driving torque of the swing arm needs to be checked.

Under the condition of the maximum lateral extension of the manipulator arm and the maximum load, we hope that the front directions of the robot should be in the same direction to the banana tree being picked. In such a condition, it could be effective to reduce the overturning risk and the driving torque required by the swinging arm.

Under this design premise, the maximum driving torque required by the swing arm is calculated to be 1000Nm. The swing arm is driven up and down by a linear electric cylinder. The swing angle design is ±30°. The effective arm length between the linear electric cylinder and the swing arm is 150mm. However, when the maximum swing angle is 30°, the effective arm length between the linear electric cylinder and the swing arm is about 125mm.

Therefore, the maximum thrust force of the electric cylinder is required to be 8KN. Finally, the driving motor of 150W (APM-SA015A, LS Mecapion Co. Ltd.) is selected, and the maximum motor output torque is 1.432nm. The motor firstly passes through an unipolar planetary reducer with deceleration ratio I =10, and then outputs the power to the ball screw module with lead L=10mm. The maximum linear thrust force is 9KN. And the maximum reciprocating telescopic speed is 50mm/s, which meets the requirements of the maximum driving torque required by the swing arm. Finally, the time required for the swing arm to swing from the equilibrium position to the limit position of ±30° is calculated to be 1.5s.

C. Design of 3-DOF Picking Arm Based on 2-DOF stable platform

The banana picking arm studied in this paper needs to maintain the vertical state of the 2-stage telescopic rod. So we adopt a 2-DOF stable platform between the moving chassis and the manipulator arm. The 2-DOF stabilization platform is designed to compensate the rolling and pitching caused by the soft soil and the posture change of the manipulator arm. It could also reduce the shaking influence on the grip-shear integrated operation handle at the end of the manipulator arm. The design of a 3-DOF picking arm based on 2-DOF stabilization platform is shown in Fig.6.

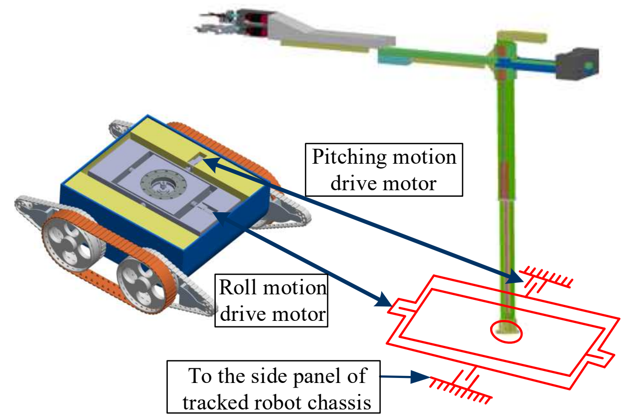


Fig.6 Design of the 3-DOF picking arm based on 2-DOF stabilization platform

The 2-DOF stabilization platform need to bear the manipulator arm weight and the terminal load weight. The manipulator arm weight designed in this paper is about 96kg, and the maximum load at the end is 80kg. Therefore, the rated load of the 2-DOF stabilization platform reaches about 176kg. Besides, the pitching movement and the side roll movement are designed to balance the inclination of the moving chassis. The pitching movement and side roll movement can be adjusted by ±30° in their respective azimuth axes.

The driving device responsible for the main rotation of the manipulator arm is nested in the center position of the 2-DOF stabilization platform as shown in Fig. 6. So that the overall manipulator can rotate 360° in the horizontal plane, while the vertical support rod can also be adjusted in the vertical direction.

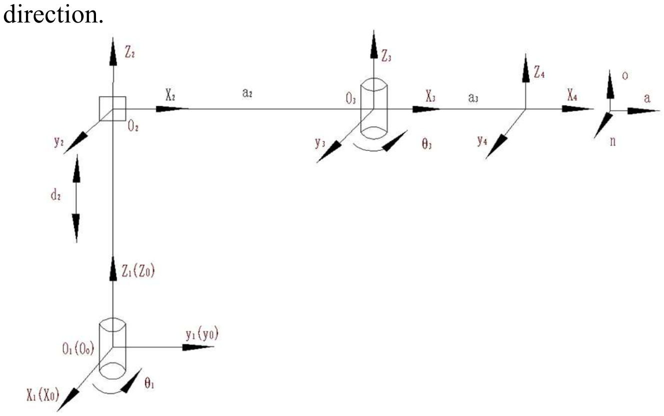


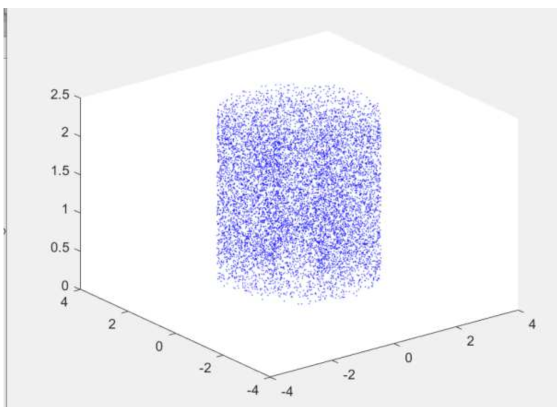
Fig.7 Degree of freedom of the 3-DOF picking arm and its kinematics coordinate system establishment

The 3-DOF picking arm can carry out 360° rotation movement in the horizontal plane. And its second motion ability is vertical up and down telescopic movement. The third motion ability is the extension/bending movement between the first-stage transverse link and the second-stage transverse link.

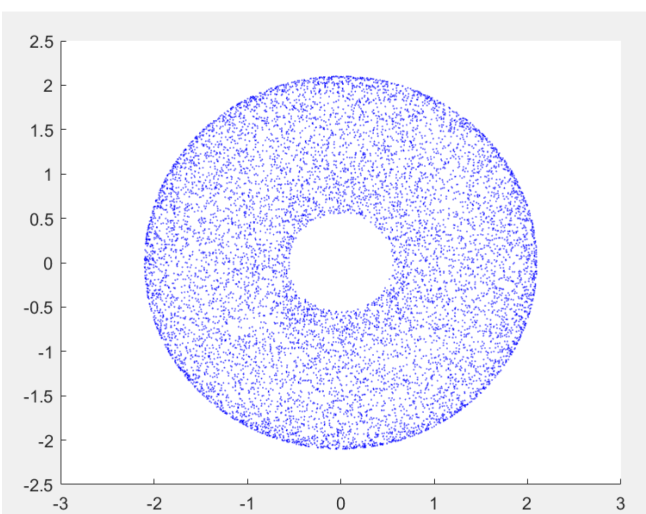
For banana clamping and cutting operations, the moving chassis of the robot remains stationary. Therefore, the overall robot movement function is mainly reflected in the 2-DOF stabilization platform and the 3-DOF picking arm. Its degree of freedom and its kinematics model are analysed as shown in Fig. 7.

The workspace of the 3-DOF picking manipulator arm is obtained by the MATLAB simulation as shown in Fig.8. The working space of the grip-shear integrated operation handle could cover the scope of around 2.1 m in diameter (excluding the center diameter 20cm). It reflects that the arm can reach any picking point position. The mechanical arm structure design is reasonable, conform to the robot design index.

In addition, the mass distribution of each connecting rod part designed by the 3-DOF picking manipulator is shown in Table 2.



（a）Three dimensional operating space



（b）XOY horizontal projection

Fig.8 Workspace of the 3-DOF picking manipulator arm is obtained by the simulation

TABLE II
QUALITY PARAMETERS OF EACH PART OF THE BANANA PICKING ROBOT PICKING ARM

Part	Weight /Kg
First-stage telescopic link	22
First-stage transverse link	5.7
The grip-shear integrated operation handle and the 2-Second-stage transverse link	12
Gravity balancing counterweight	50
Two stage synchronous telescopic drive device in the vertical direction	7
Payload - banana skewers	80

D. *Grip-shear integrated operation handle design*

The grip-shear integrated operation handle at the end of the banana picking arm is divided into two parts, including the clamping mechanism and shear mechanism. Considering the shape and physical characteristics of the banana pseudosperm, the clamping mechanism should have certain envelopment. Combined with the banana pseudosperm thickness, it is necessary to make the clamping mechanism reach the maximum contact area under the permissible state.

At the same time, the banana pseudosperm may slide with the clamping mechanism, or even slide. So its grasping force needs to meet the actual use requirements. The clamping mechanism is required to withstand the gravity of 30-80kg. There are two main configurations of clamping mechanism: translational type and rotary type. The rotary type clamping mechanism has a larger contact area with the banana pseudosperm and it can also achieve a larger clamping angle by adjusting the switch closing angle. This feature is convenient for the clamping. Therefore, the clamping mechanism configuration is selected back to the rotary type. The schematic diagram of its movement principle is shown in Fig.9.

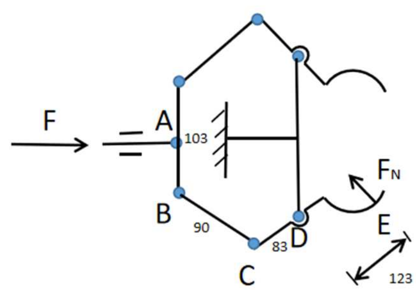


Fig.9 The schematic diagram of the clamping mechanism

The shear force of the grip-shear integrated operation handle should meet the requirements. The structure of banana pseudosperm can be divided into outer cortex, middle xylem and phloem, among which the cortex structure is more compact. In order to achieve the shear requirements, the shear mechanism needs sufficient shear force. According to the data obtained from the prickling experiment of banana pseudosperm[8], the shear force is proposed to be greater than 20kg.

The shearing mechanism is mainly composed of shearing tool, linear guide rail, ball screw module and mounting frame. When the motor and the ball screw rotation drive the screw nut to move back, the cutting tool is relaxed. When the motor and the ball screw are reversed, the shearing tool is closed and the shearing is performed. The overall design of the grip-shear integrated operation handle is shown in Fig.10.

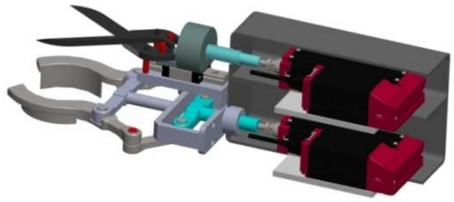


Fig.10 Design of the grip-shear integrated operation handle

IV. Robot Control System Hardware Platform

Fig.11 shows the hardware platform structure of the robot control system. The upper computer uses embedded master controller based on ARM/DSP to control the robot. In this study, the TMS320F28335 high performance DSP chip with floating point operation unit and the ARM chip STM32F103 with Contex-M3 core were selected.

The robot is powered by a 48V lithium battery pack equipped with DC-DC transformer module to power ARM/DSP embedded master controller and related sensing and detection system. The DC-DC transformer module reduces the 48V DC voltage to 5V, which is provided to the embedded master controller of the upper computer and the CAN communication node.

The CAN bus information acquisition node mainly integrates an attitude sensor unit composed of a three-axis accelerometer, a three-axis gyroscope and a three-axis electronic compass, which could detect the attitude of the robot track chassis.

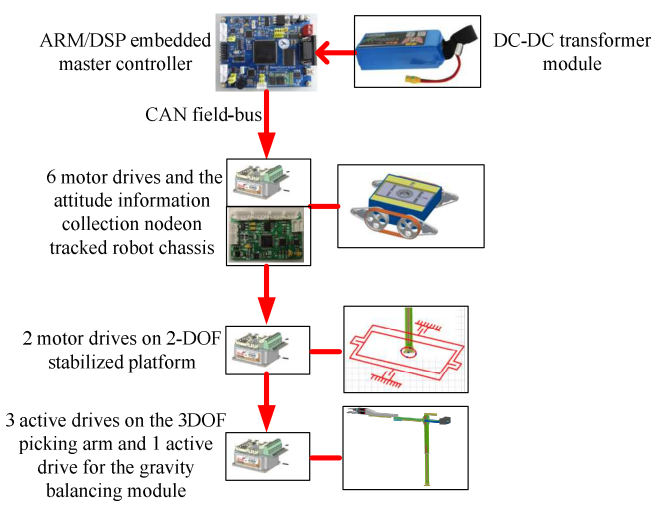


Fig.11Hardware platform structure of the robot control system

All the motor drivers of the robot and the attitude information acquisition node on the robot track chassis communicate with the main controller through CAN bus. The motor drivers include 6 drivers on the moving chassis, 2 drivers on the 2-DOF stabilization platform, 3 drivers on the 3-DOF picking manipulator arm, and 1driver on the gravity balance module. As a result, there are 13 CAN nodes in the robot control system, and each CAN node is assigned different address.

V. Conclusion And Future Work

In this paper, an automatic banana picking robot based on 2-DOF stabilized platform is designed for banana picking. Firstly, the planting environment of banana tree and the action sequence needed to be completed for picking were analyzed. Then the overall configuration design of the robot is determine. There are three main components of the picking robot according to the design scheme, including the robot moving chassis which can adapt to the complex ground environment in the field, a mechanical arm with large span operation ability in the vertical direction and the horizontal direction, and a grip-shear integrated operation handle at the end of the manipulator arm. The 2-DOF stabilization platform is designed to compensate the rolling and pitching caused by the soft soil and the posture change of the manipulator arm.

Through the statics analysis of the ultimate working state, the performance parameters of the main drive track and the four swing arms are obtained, which meet the practical application requirements. A complete hardware platform structure has also been established. The next step focuses on the 2-DOF stabilized platform control. It is expected that the appropriate control methods of 2-DOF stabilized platform can accurately make up the attitude changes and interference by the robot moving chassis and the picking manipulator arm.

Acknowledgment

This research is supported by “The Dongguan Special Emergency Research And Promotion Program For Epidemic Prevention Technology Specific To New Coronavirus Infection Pneumonia” (No.2020717140122) and “The Agricultural science and technology Innovation and Promotion Program of Guangdong 2019” (No.2019KJ139).

References

[1] Li Xiaobin, Wu Hongqi, Chen Weihong, Zhang Li, “Design and simulation of a joint servo control system for an apple-picking robot,” Computer Measurement and Control, vol. 29, no. 3, pp. 129-134, 2021.

[2] Y. Sariy, “Robotics of fruit harvesting: A state of the art review,” Journal of Agricultural Engineering Research, vol. 54, pp. 265-280, 1993.

[3] Xu Zhenzhen, Sun Jie, Zhao Liang, “Classification, integration of preliminary processing technology in banana producing areas of China,” Transactions of the Chinese Society of Agricultural Engineering, vol. 31, Supp.1, pp. 332-336, 2015.

[4] Zhu Dongyun, Qu Junyuan, Xu Lueqiang, Zhang Zhenbao, Ji Xiang, “Disign of banana pinking machine structure with guide rail,” Food and Machinery, vol. 34, no. 1, pp. 92-94, 2018.

[5] LI Yuehan, Wu Hewei, Zhang Wu，Chen Xin, Shi Zhihui, “The Design of All-directional Pneumatic Fruit Picking Machine Based on ROBO.TXT Control,” Mechanical & Electrical Engineering Technology, vol. 47, no. 8, pp. 127-129, 2018.

[6] Zhang Genge, Ding Yuan, Huang Xiaojin, “Design of a Banana Picking Device,” Automobile Applied Technology, vol.9, no.8, pp.150-153, 2020.

[7] Su Jilong, Liu Yuanli, Wu Jindong, “Research status and development trend of banana picking machine,” Journal of China Agricultural University, vol.24, no.7, pp.131-137, 2019.

[8] Wang Hongjun, Tang Zhifu, Zhao Runmao, Zou Xiangjun, “Simulation and Optimization Design of Holding Device for Banana Picking Manipulator,” Machinery Design ＆ Manufacture, vol.6, pp.161-164, 2015.