2023 ASABE Student Robotics Challenge
Robot Design Report

Division : Beginner

Team Name : Team D.A.D

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Catalog

1 Team Members

In preparation for the 2023 ASABE Student Robotics Challenge, we founded a team of five undergraduate students. The members have different specialties and characteristics, but all share the same passion for robotics. With our combined efforts, the design, construction and testing of the robot has been completed. The details of the members are listed below.

Table 1-1 Profiles of team members

Name	Specialties	Assigned tasks	Identity
Antian Zhao	·Computer Vision ·Embedded System Design ·Programming and Debugging ·SolidWorks 3D Modeling	· Identification Module Design · Operation Module Design · Tracking Module Design · Arduino Software Design	Junior Captain
Huhang Jin	·SolidWorks 3D Modeling ·SolidWorks Model Rendering ·Mechanical Design and Assembly	· Motion Module Design · Operation Module Design · Assembly and Rendering	Junior Member
Huizi Lu	·Sensor Applications ·Embedded System Design ·Programming and Debugging	· Tracking Module Design · Arduino Software Design ·Hardware Processing	Junior Member
Yiwei Huang	·PCB Design ·Hardware Welding ·Programming and Debugging	· Circuit Module Design · Arduino Software Design · Tracking Module Design	Sophomore Member
Hongyuan Liu	·Copywriting ·SolidWorks 3D Modeling ·Sensor Applications	· Report Writing · Operation Module Design · Bookkeeping and Reimbursement	Junior Member

2 Establishment of Need and Benefit to Agriculture

2.1 Cultivation of the cotton plant

Cotton is a widely cultivated crop that is grown for its soft and fluffy fibers. The cotton plant is native to tropical regions, where it can grow as a perennial tree-like plant. However, in temperate climates, it is typically grown as a shrubby annual.

After planting, it takes around 80 to 100 days for the cotton plant to develop white blossoms, which later turn reddish. Once fertilized, the blossoms fall off after a few days, and small green triangular pods, known as bolls, begin to grow. These bolls mature over a period of 55 to 80 days, and when they ripen, they burst open to reveal a white, fluffy ball containing three to five cells, each containing 7 to 10 seeds embedded in a mass of seed fibers. The seeds make up about two-thirds of the weight of the seed cotton, while the remaining weight is made up of the fibers.

To avoid damage to the cotton caused by wind or rain, the bolls are picked as soon as they open. However, since the bolls do not all mature at the same time, an optimum harvesting time is chosen to ensure that the majority of the bolls have ripened. Mechanical means are used for harvesting, and a chemical defoliant is typically applied before picking to encourage the plants to shed their leaves, which helps with more uniform ripening of the bolls.

Despite these measures, some unopened cotton bolls can still be damaged during harvesting, which reduces the overall yield and quality of the cotton. Therefore, farmers must carefully monitor their crops and employ the most effective harvesting techniques to ensure a successful cotton harvest. Overall, cotton cultivation is a complex process that requires careful attention to detail and a deep understanding of the plant's biology and environmental needs.

Figure 2-1 Unripe Cotton

Figure 2-2 Ripe Cotton

2.2 The importance of mechanical cotton picking

Cotton has played a significant role in the history of the world, with entire regions being built around its production. Even with the advancements in technology over the past few centuries, cotton remains a vital commodity in many regions, and countless people depend on its cultivation and harvest for their livelihoods. One of the biggest challenges faced by cotton farmers is the need to harvest large amounts of cotton within a reasonable timeframe to ensure maximum yields and profits.

In the past, farmers relied on laborers to pick cotton by hand, which was a time-consuming and labor-intensive process. However, the invention of the mechanical cotton picker revolutionized the industry. With a mechanical cotton picker, farmers could harvest cotton in a fraction of the time it would take to do so by hand while also reducing labor costs significantly. This increased production and harvesting capability had a massive impact on the cotton industry and the textile industries that rely on cotton as a raw material.

The introduction of mechanical cotton pickers not only increased efficiency and profitability but also had a profound impact on the social and economic aspects of cotton farming. With the use of mechanical cotton pickers, farmers could harvest more cotton with fewer workers, which allowed them to expand their operations and increase production. This, in turn, led to the creation of new jobs and increased economic opportunities in regions where cotton was a vital crop.

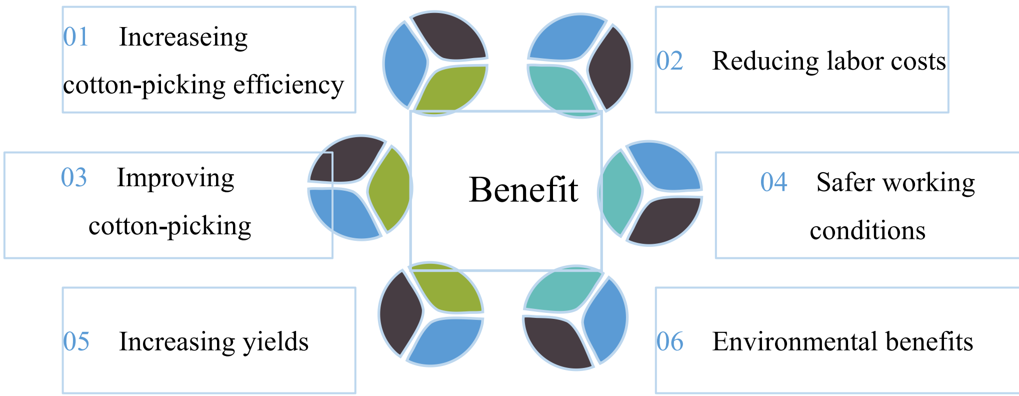
Furthermore, the use of mechanical cotton pickers also helped to reduce the physical strain and health risks associated with manual labor, making cotton farming a safer and more sustainable profession. Overall, the importance of mechanical cotton picking cannot be overstated, as it has played a crucial role in the growth and development of the cotton industry, benefiting not only farmers but also consumers worldwide who rely on cotton for a wide range of products.

(a) **(b)**

Figure 2-3 Cotton Picking

2.3 Benefit to Agriculture

Mechanized cotton picking has revolutionized agriculture, particularly in the cotton industry. It has significantly improved efficiency and productivity while reducing labor costs and the physical strain on workers. Here are some of the benefits of mechanized cotton picking:



(1)Increasing cotton-picking efficiency: Mechanical cotton pickers can harvest a significantly larger area of cotton fields than manual laborers in the same amount of time. This means that farmers can harvest more cotton in less time, which leads to increased productivity and profitability.

(2)Reducing labor costs: The use of mechanical cotton pickers reduces the need for manual labor, which is usually the most significant expense in cotton farming. By reducing labor costs, farmers can save money and invest in other areas of their operations.

(3)Improving quality: Mechanical cotton pickers are designed to harvest only the mature cotton bolls, leaving the immature and damaged ones behind. This results in higher quality cotton, which can command higher prices in the market.

(4)Safer working conditions: Manual cotton picking can be a physically demanding and labor-intensive job, which can lead to physical strain and injuries. Mechanized cotton picking reduces the physical strain on workers, making cotton farming a safer and more sustainable profession.

(5)Increasing yields: Mechanical cotton pickers can harvest cotton at a faster rate than manual laborers, which means that farmers can harvest more cotton in a shorter time. This can result in higher yields, which can translate into higher profits for farmers.

(6)Environmental benefits: Mechanized cotton picking reduces the amount of time that cotton is left in the fields after maturing, which can reduce the risk of pest infestations and diseases. This can result in a lower need for pesticides and herbicides, which can reduce the environmental impact of cotton farming.

3 Definition of Design Objectives and Criteria

The robot to be designed for this competition should have the ability to recognize the ripe cotton and immature cotton ,pick ripe cotton and transport the picked cotton to the designated location ,complete the counting display. In order to achieve the goal perfectly, a detailed and specific division was made to complete the task efficiently and accurately. The sub-points are as follows：

(1) Robot needs to have a navigation function without guidelines.

(2) Precise identification of white cotton and unopened cotton boll which is replaced by green ping pong balls in the competition,and store the identification result in USB driver.

(3) Harvest and store cotton while avoiding damageing to the hull or unopened boll.

(4) The robot should work independently, without any external communication or human intervention.

(5) Tracing in the absence of guidelines and ridges though there are guidelines.

(6) The machine can automatically collect cotton into the storage device.

(7) No human intervention to the robot.

(8) Max robot size of 12'' × 12'' × 12'' at the start of each time trial.

4 Approach and Originality

4.1 Approach

4.1.1 Hardware

We have broken down the overall objective into five design modules: the operation module, the motion module, the circuit & electronic components module, the tracking module, and the identification module. This modular design approach allows us to work with clearer objectives and facilitates the division of labor, management and schedule advancement.

Therefore, we use a rotating screw to wrap and rotate the cotton around the screw, and after it is completely wrapped, we separate the cotton from the cotton shell by retracting it backwards. To facilitate the separation of the cotton from the screw, we use an aluminum tube to block most of the screw threads, and also design a separation device to improve the separation rate. After collecting cotton, there will be a temporary box for storing cotton, and after completing some of the operations, the collected cotton will be placed at the destination first, and then the remaining cotton will be collected.

4.1.2 Software

The prerequisite for automatic completion of all cotton-picking work is successful tracing. In the tracing module, we use ultrasonic sensors to determine the robot's location and correct the robot's position offset by controlling stepper motors via Arduino. An infrared sensor is used to determine whether it reaches the end of the row and makes a turn. In the identification module, we use another infrared sensor to identify the plant stems and use the camera controled by Jetson Nano to determine the cotton and unopened cotton balls are located.After transmitting the identification information to the Arduino, the Arduino will control the operation module and the motion module to perform the harvesting operation.

4.1.3 Ultrasonic and Infrared Positioning System

The robot stops at the required location through infrared detection, and adjusts the parallelism between the robot and the field board by measuring the distance with two ultrasonic sensors, enabling more precise operations.

4.1.4 Drill-type

The drill-type structure is used for picking to reduce damage to the cotton itself. Furthermore, by reversing the rotation, the cotton can be easily separated, allowing for efficient and simple picking and collection. Additionally, due to the drill's sufficient length and relatively thin size, it can easily cover the entire cotton boll, thereby increasing the efficiency of picking.

4.1.5 Transport and Collection of Cotton

We plan the transportation route reasonably to store and transport the cotton with maximum efficiency. After picking a portion of the cotton, it will be transported to the destination before continuing with the next step of picking.

4.1.6 Black Appearance

The black appearance helps to distinguish between the cotton and the robot, thereby aiding in better identification of the cotton.

5 Parts List and Table

As shown in Table 5-1, the total cost of our robot was $414.79[1]. The processor device we used was Arduino and Jetson Nano, which cost $184.9,　less than the $200 limit set by the organizers.

Table 5-1 Parts List and Cost

No.	Item	Type (Spec)	Qty	Unit Price (RMB)	Total Price (RMB)
1	Arduino	Mega2560 Pro ATmega2560-16AU	1	68 （$9.5）	68 （$9.5）
2	Jetson Nano	4GB-B01	1	1259 （$175.4）	1259 （$175.4）
3	42 Stepper Motor	42BYGH47	4	69	276
4	Stepper Motor Frame	42 Stepper Motor	4	2.04	8.16
5	42 Stepper Motor Driver	/	4	26.9	107.6
6	DC Motor	GW4632BL2838	4	65	260

[1] According to the exchange rate on June 30.

		12V 34r/min			
7	Servo	32kg	6	34.9	209.4
		RoSH/8Kg	2	20.9	41.8
8	Printed Circuit Board	Customized	1	11.8	11.8
9	Infrared Sensors	/	1	2.5	2.5
10	Ultrasonic Sensor	HC-SR04	2	4.4	8.8
11	Camera	3 million pixels	1	49	49
12	Ultrasonic Sensor Frame	/	2	2.5	5
13	Carbon Fiber Plate	5mm/Customized	1	359	359
14	Acrylic Plate	5mm/Customized	1	79	79
15	Copper Pillar	40mm/60mm/ 65mm/70mm/90mm	/	/	15
16	Screw	4mm*10/4mm*15	/	/	8
17	Nut	4mm/3mm	/	/	6
18	4S Battery	4S 16.8V	1	49.9	49.9
19	3D Printing Material	Photosensitive Resin	2	78	156
20	Angle Iron	Type 20	12	1.5	18
21	Wires	/	/	/	10
	Sum	3007.96￥ /414.79＄			

6 Hardware Description

In order to meet the requirements of the competition task, we have designed picking device、separation device、collection device、telescopic device.

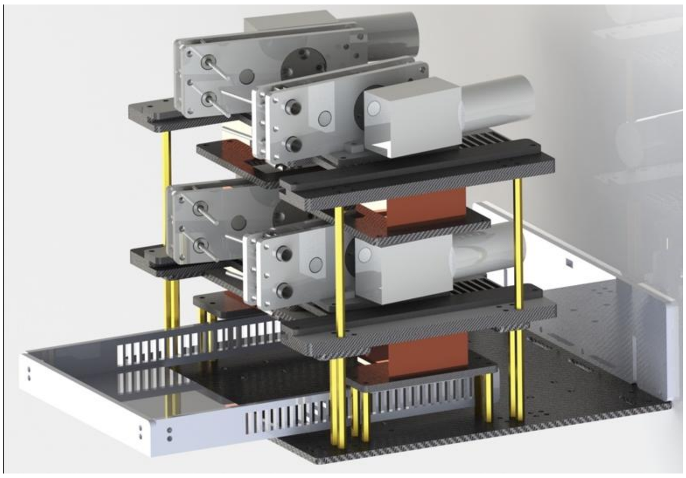
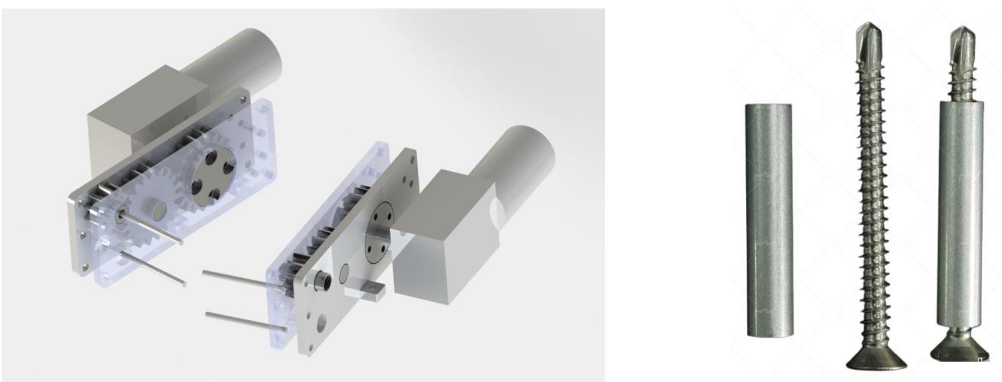


Figure 6-1 Robot schematic

6.1 Operation Module

6.1.1 Picking Device

The cotton is picked using a drill-like structure that imitates a drill bit with a screw at the end and an aluminum tube. The cotton is picked by the sharp tip of the drill bit and the smoothness of the aluminum tube while avoiding tightly wrapping the cotton. The picking mechanism is extended by gears, and the cotton is picked up by rotating the drill bit and then releasing it.



(a)Overall picking model (b) Drill and Aluminum Tube

Figure 6-2 Picking Device

6.1.2 Separation Device

Due to the smooth surface of the aluminum tube, a brush-like structure is used to apply a horizontal force to the cotton to make the cotton fall off the drill bit on both sides. We use a 3D-printed brush with high rigidity to ensure that the cotton can be easily separated from the drill bit, rather than remaining on the drill bit and affecting subsequent picking.The separation mechanism moves to the far right end, and the telescopic device on the right stretches the picked cotton back.①Rotate it to the middle position to separate the cotton from the picking mechanism;

The separation mechanism moves to the far left end, and the left telescopic mechanism stretches the cotton back. ② rotates to the middle position to separate the cotton from the picking mechanism.

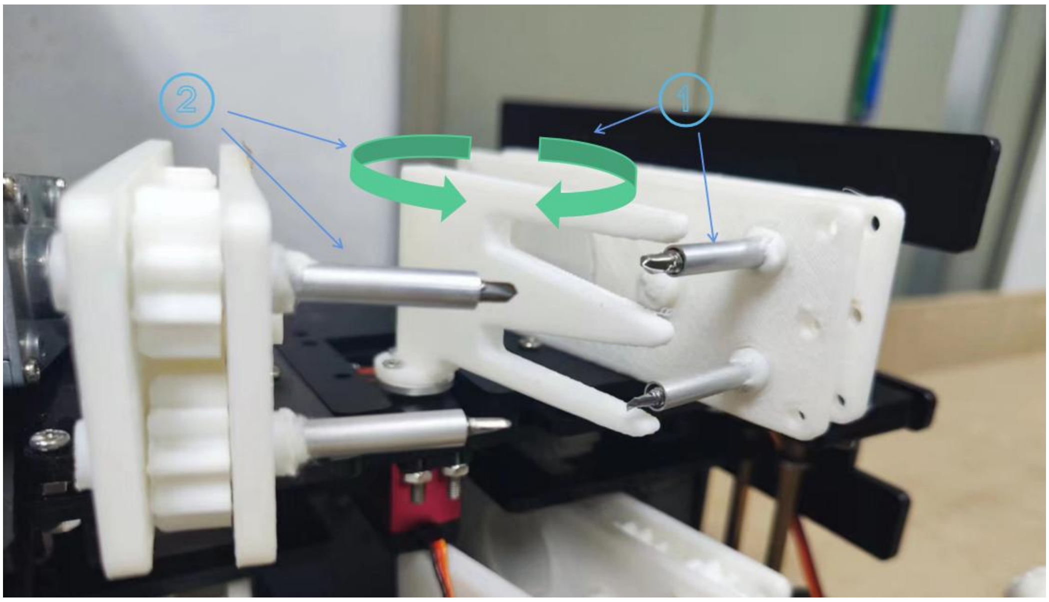


Figure 6-3 Separation Device

6.1.3 Collection Device

Due to the size limitation of the robot and the large occupation of the execution mechanism, it was found through calculations and preliminary practice that it was not possible to collect all the picked cotton at once. Therefore, we chose to use a smaller collection device and unload the cotton multiple times to ensure the normal collection process. The basket is extended out by gears to collect the cotton and then retracted to the back. At the designated location, the back plate is opened to allow the cotton to enter the collection corner.

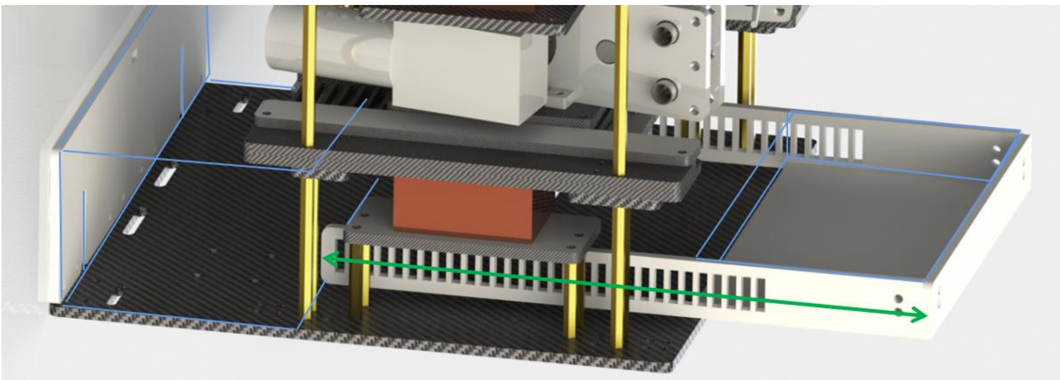


Figure 6-4 Collection Device

6.1.4 Telescopic Device

We use a telescopic device to perform telescopic motion on the picking mechanism. The steering gear drives the movement of gears through rotation, and the expansion and contraction movement of carbon fiber board is driven by the rotation of gears. The picking mechanism is fixed on the carbon fiber board of the telescopic mechanism for back and forth movement.

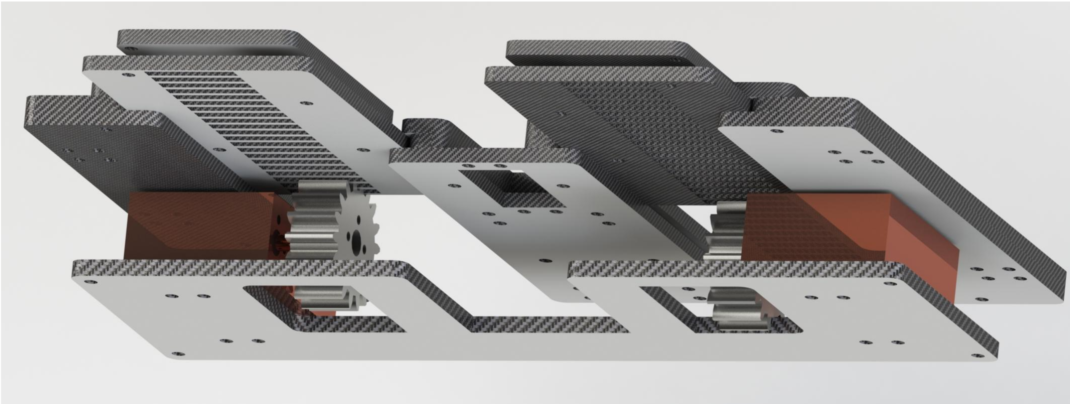


Figure 6-5 Telescopic Device

6.2 Motion Module

6.2.1 Harvesting Motion

The motion of the cotton picking mechanism includes extension, rotation, and retraction. We use a gear rack mechanism driven by a servo motor to achieve the extension and retraction of the picking mechanism. To accurately control the position of the picking mechanism and ensure a large adjustable range, we chose a 360° fully controllable angle 32KG T-Motor servo. For the rotation motion of the picking mechanism, we use a DC motor, and appropriate transmission ratios are obtained through multiple gear transmissions. Since insufficient torque may not be able to wrap tightly attached cotton, and excessive torque may damage the cottonseed and occupy too much space, we choose a DC motor with a torque of 8 Kg •cm through testing, which can meet the requirements of picking while minimizing the space and weight occupied by the robot.

6.2.2 Separation Motion

The motion of separating the cotton from the picking mechanism includes the unilateral extension of the picking mechanism, rotation of the separation device, and unilateral retraction of the picking mechanism. The unilateral extension and retraction of the picking mechanism are similar to the cotton harvesting operation. The separation device requires a small rotation angle, and a small force can meet the separation requirements. Therefore, we chose a servo motor with a controllable angle of 180° .

6.2.3 Driving Motion

We choose omni wheels with stepper motors to drive the robot to move. The installation method is shown in Figure 6-18. Each pair of omni wheels drives the motion in one direction, and when it is to move forward, only the omni wheels #2 and #3 are controlled to rotate. At this time, the sub-wheels on wheels #1 and #4 are forced to rotate, which can play a role in reducing friction. The same way when it wants to move left and right. With the help of such wheels, the robot can make vertical turns without changing the direction of the body, and it will be easier to code for turning. The type of stepper motor is 42HB40-401A, which uses PWM to precisely control its rotation steps, with low heat generation and good efficiency.

Figure 6-6 Stepper MotorII

Figure 6-7 Omni Wheel

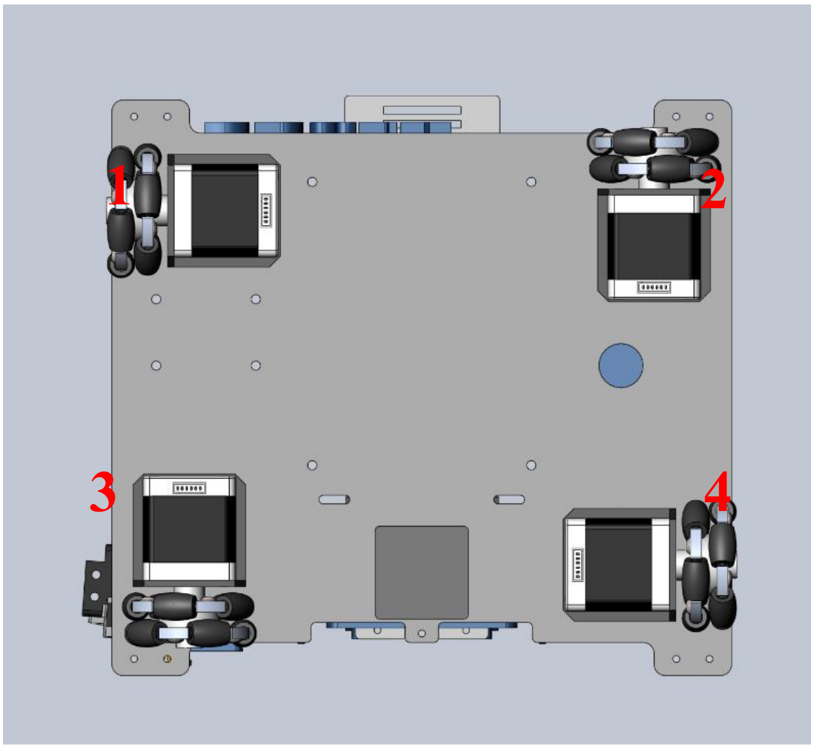


Figure 6-8 Base Plate

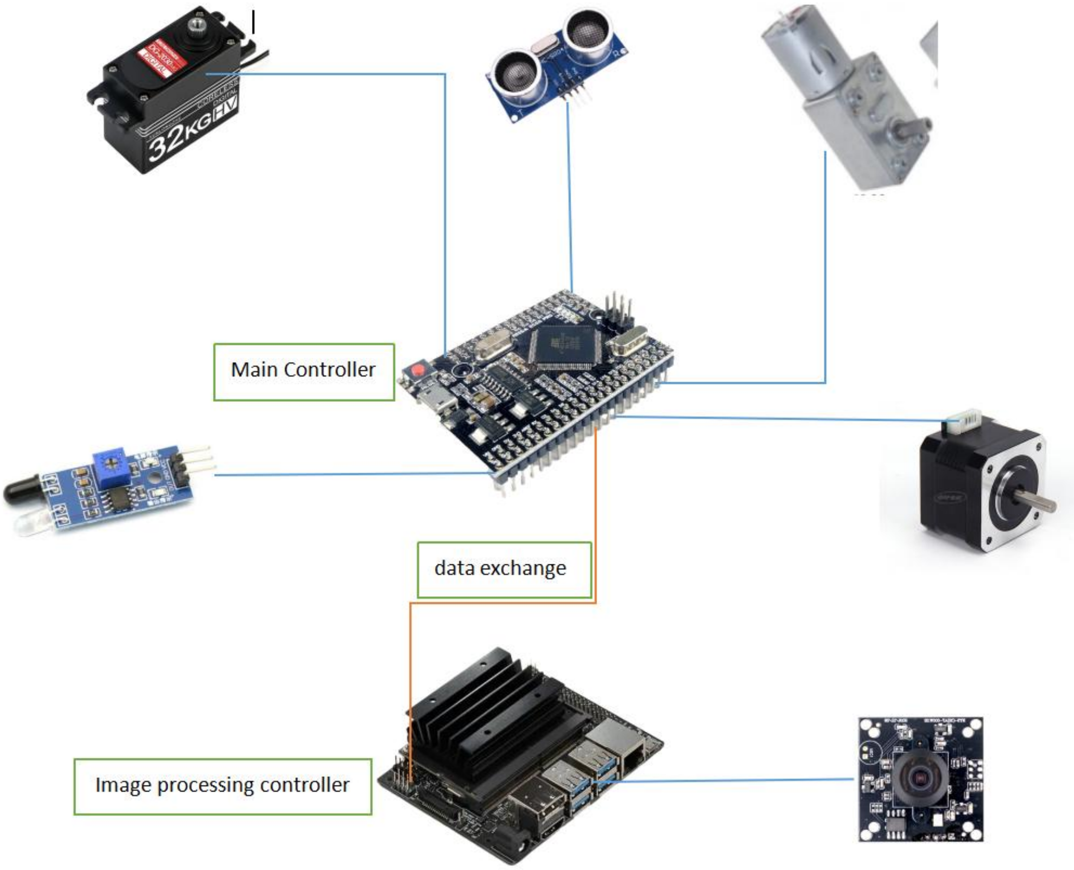


Figure 6-9 Schematic diagram of the hardware connection

6.3 Circuit & Electronic Component Module

6.3.1 Jetson Nano

Jetson Nano B01 is a compact computer module designed for AI and robotics applications. It is powered by an NVIDIA Maxwell GPU with 128 CUDA cores and a quad-core ARM Cortex-A57 CPU, making it capable of performing complex AI computations and running multiple applications simultaneously.

The Jetson Nano B01 module features 4GB of LPDDR4 memory, a microSD card slot for additional storage, Gigabit Ethernet, and support for multiple USB 3.0 and USB 2.0 ports. It also includes a dedicated MIPI-CSI camera connector and HDMI display output for video capture and display capabilities.

This highly versatile module is ideal for a wide range of AI and robotics applications, including object detection, image classification, speech recognition, and autonomous navigation. It can be used in a variety of devices, from small robots to intelligent cameras and drones.

The Jetson Nano has such excellent performance that we use it as our image processing module for picking mature and immature cotton.

6.3.2 Arduino

Arduino is an open-source electronics platform based on easy-to-use hardware and software. It consists of a programmable microcontroller board, which can be used to create a wide range of interactive objects and projects.

Arduino boards are programmed using the Arduino Integrated Development Environment (IDE), which is a user-friendly software application that allows users to write and upload code to the board. The IDE includes a range of libraries and examples that simplify the process of programming and enable users to quickly get started with their projects.

We use Arduino as the main controller to collect data information from various sensors and control various actuators.Arduino also communicates with Jeton nano to obtain image data information processed by Jetson nano.

Figure 6-10 Jetson Nano

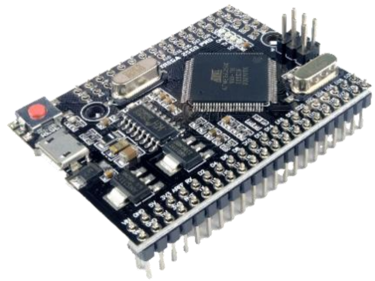


Figure 6-11 Arduino

6.3.3 Ultrasonic Sensors

An ultrasonic sensor is a type of sensor that uses ultrasonic waves to detect objects and convert them into electrical signals. It is commonly used for distance measurement due to its high frequency, short wavelength, and good directionality.

When in operation, the ultrasonic sensor emits ultrasonic waves in a particular direction and starts timing. When the ultrasonic wave hits an object, a reflection echo is formed, and the receiver stops timing as soon as it receives the reflected wave. The distance between the launch point and the obstacle can be calculated using the propagation speed of ultrasonic waves in the air and the flight time of the ultrasonic waves.

Ultrasonic sensors are widely used in various applications, including automotive parking assist systems, robotics, and industrial applications. They are preferred in environments where optical sensors may not be suitable, such as dusty or smoky environments. Additionally, they consume low energy and are relatively inexpensive, making them a popular choice for many applications.

6.3.4 Infrared Sensors

Infrared sensor is a type of sensor that uses infrared light to detect objects and convert them into electrical signals. It consists of an infrared transmitting and receiving tube. The transmitter tube emits infrared light of a particular frequency, which is then reflected by an obstacle (reflective surface) and received by the receiving tube.

Infrared sensors are commonly used in a variety of applications, including proximity sensing, object detection, and motion detection. They are preferred in environments where other types of sensors, such as ultrasonic sensors, may not be suitable. Infrared sensors have strong adaptability to environmental light and strong anti-interference ability, making them reliable in various conditions

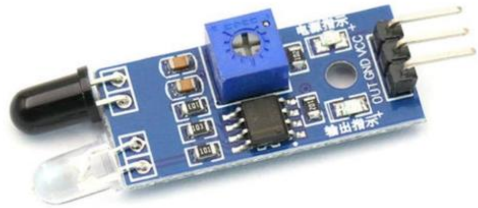


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Figure 6-12 Ultrasonic Sensors **Figure 6-13** Infrared Sensors

6.3.5 Printed Circuit Board

We have developed a custom printed circuit board (PCB) that can connect a microcontroller and other electronic components. This PCB is versatile and has a wide range of interfaces, making it suitable for use in various types of robots.

The PCB includes a Mega2560 Pro Atmega2560-16AU intelligent electronic development board, which is embedded in the design. To power the electronic development board and other external sensors, we have included a 5V voltage regulator module. Additionally, two DC adjustable voltage regulator modules are included, which can adjust the voltage to 6V and 12V respectively. These voltage regulators can supply power to external devices such as servos and motors, providing the necessary power for their operation.

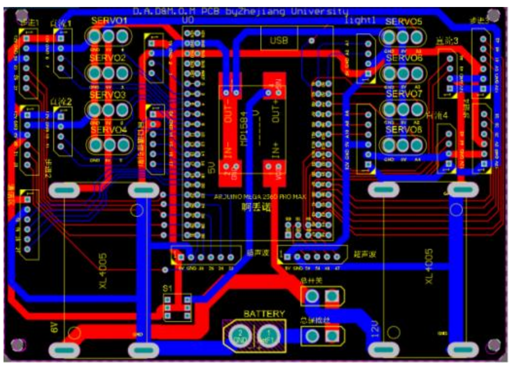


Figure 6-14 PCB circuit board

6.3.6 Camera

We chose a commercial camera(720P-1280 × 720-mjpg/30fps) for image processing of the target plant. By acquiring the plant image through the camera and using the powerful computing power of Raspberry Pi to implement more advanced algorithms, we can identify the target more accurately.

6.3.7 Stepper Motor

The crawler is driven by Tokugawa's 42HB40-401A stepper motor. This motor works under the drive circuit, has low heat generation and high efficiency, and can adjust the current level according to the actual situation, so that it can emit more energy in a compact space.

The 42HB40-401A stepper motor is a two-phase four-wire system with a torque of 0.31 N·m, rated current of 1.2 A, phase resistance of 3.3 Ω, phase inductance of 5.4 mH, and a mass of 0.22 Kg with a body thickness of 33.5mm.

Figure 6-15 Camera

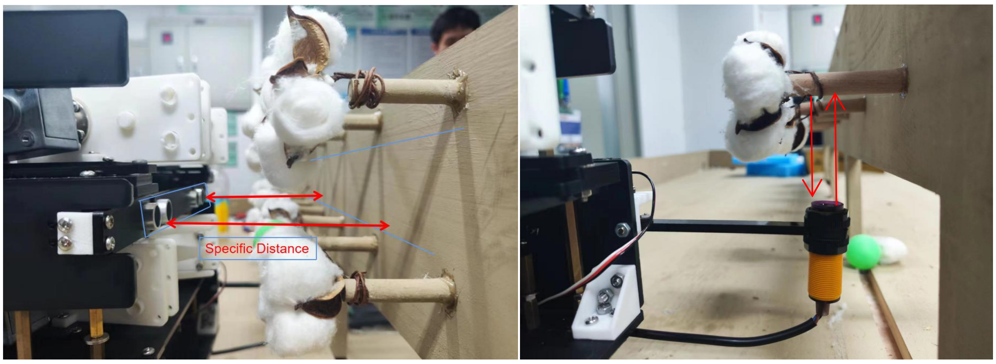
Figure 6-16 Step Motor

7 Software Overview

7.1 Tracking Module

The competition field has tracking navigation lines only in the first three rows, while the last three rows do not have them, presenting a significant challenge to the classic tracking approach. We chose to use ultrasonic sensors as the main tracking sensors, with infrared sensors as auxiliary tracking sensors. The ultrasonic sensor is used to determine whether the robot is entering or exiting the furrow, and to adjust the movement by detecting the distance between the robot and the field board. Also, the pose of the robot is determined by the values returned by the front and rear ultrasonic sensors to perform rotation adjustment. The infrared sensor is used to determine the position of the wooden stake, allowing the robot to stop accurately at each wooden stake position, ensuring the accuracy of recognition and picking. Since the ultrasonic measurement has a certain angle range, we set a suitable threshold to distinguish three situations: “in the furrow”, “partially in the furrow”, and “outside the furrow”.

Since the Arduino operates on a single thread, using analog ultrasonic sensors can cause lag. Therefore, we adopted a solution that minimizes simultaneous movement and ultrasonic measurement. When outside the furrow, to avoid blind walking, the robot needs to move and measure ultrasonic almost simultaneously. We reduced the frequency of ultrasonic measurements to reduce lag. Inside the furrow, we conduct ultrasonic measurement and adjustment only when the infrared sensor detects the wooden stake, avoiding lag and achieving better tracking results.



(a)Ultrasonic Detection (b)Infrared detection

Figure 7-1 Tracking Mode

7.2 Cotton & BollIdentification Module

When the robot stops, Jetson Nano receives command signals sent by Arduino through serial port. Based on this, it exits the waiting loop and calls two cameras to take pictures and save them for subsequent identification. The identification process mainly consists of three steps:

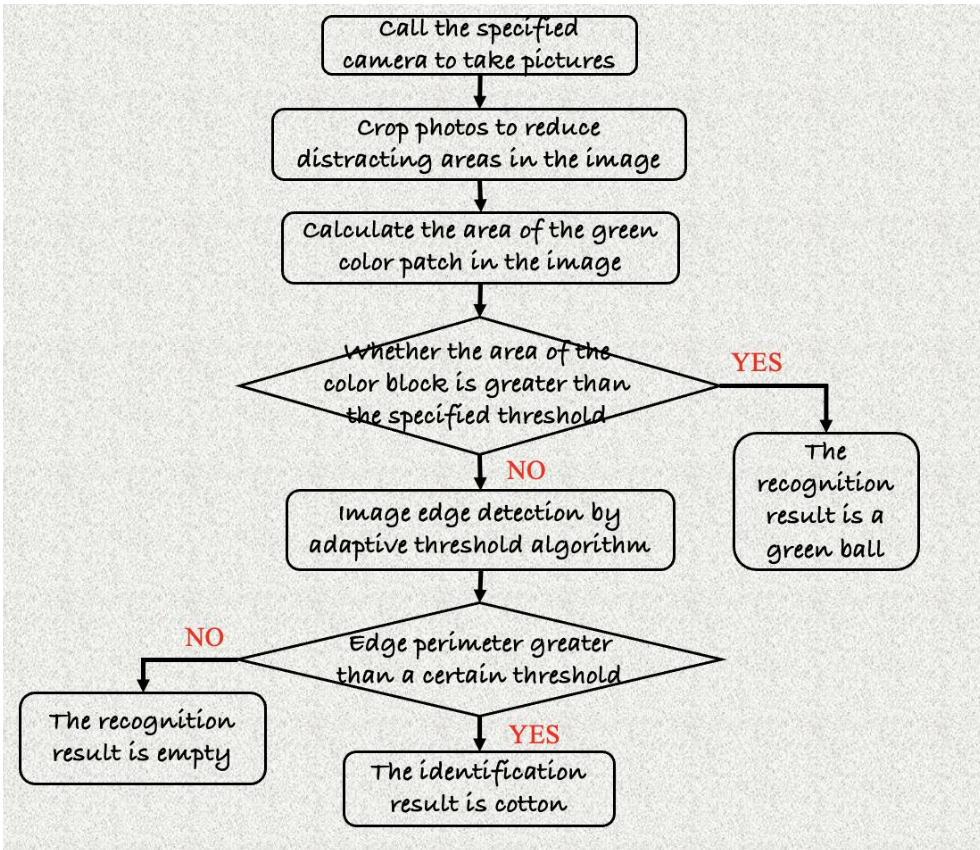


Figure 7-2 Identify Flow

7.2.1 Image preprocessing

The images captured by the cameras are cropped to reduce interference in the pictures.

7.2.2 Boll detection

Because the color of the field boards is light yellow and significantly different from the green bolls, theoretically, we can use color recognition to detect the object. If the number of green pixels exceeds a certain threshold, we can determine the object as a boll, which is an immature cotton boll.

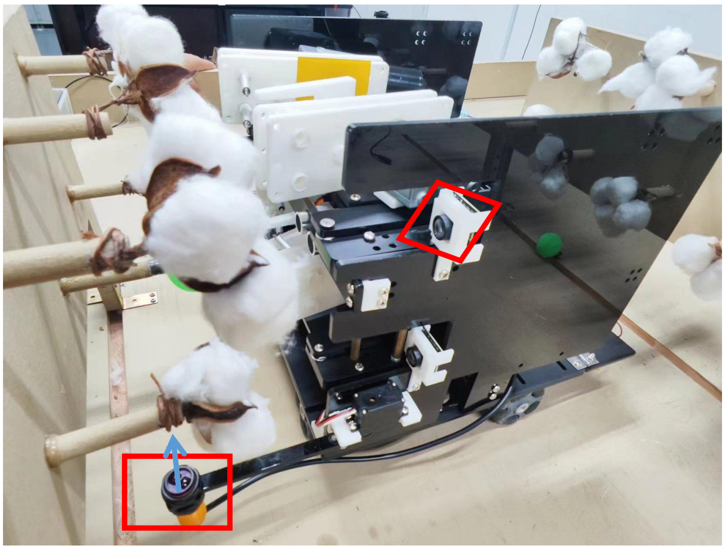


Figure 7-3 Detection Rod and Shooting

7.2.3 Cotton detection

When a green boll is not detected in the previous step, we perform cotton detection. Since we have eliminated the interference of bolls, we need to consider the significant differences between cotton and the wooden stake in the image, as well as the stability of this difference under different environments. Therefore, we finally adopt the method of "edge detection" plus extracting the length of the edge in the image to distinguish them. For cotton, there are many edges in the image due to its cotton ball, calyx, and other components, while for the wooden stake without cotton, the background is very flat, and no edge items will be detected. At the same time, we use the "watershed algorithm" to focus more on the edge items in the image and reduce the influence of environmental light through adaptive thresholding.

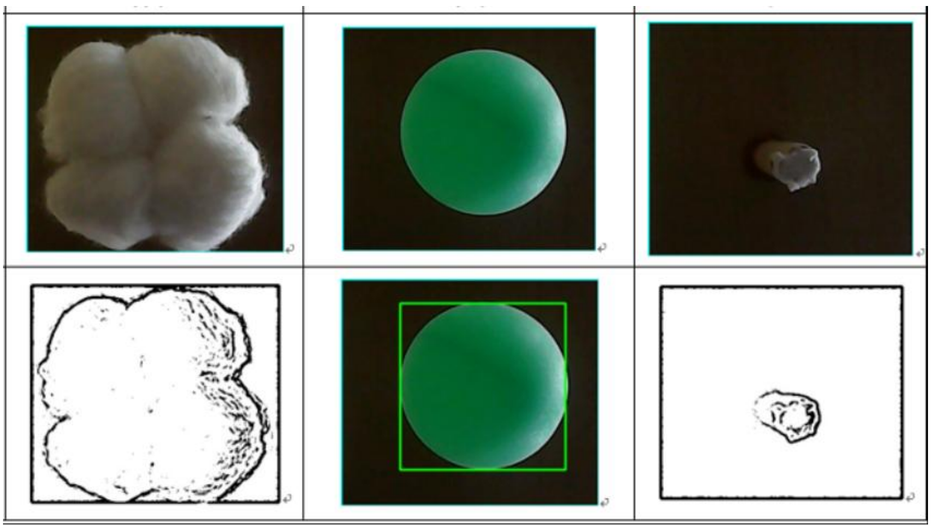


Figure 7-4 Identification Results

7.3 Overall Software Workflow

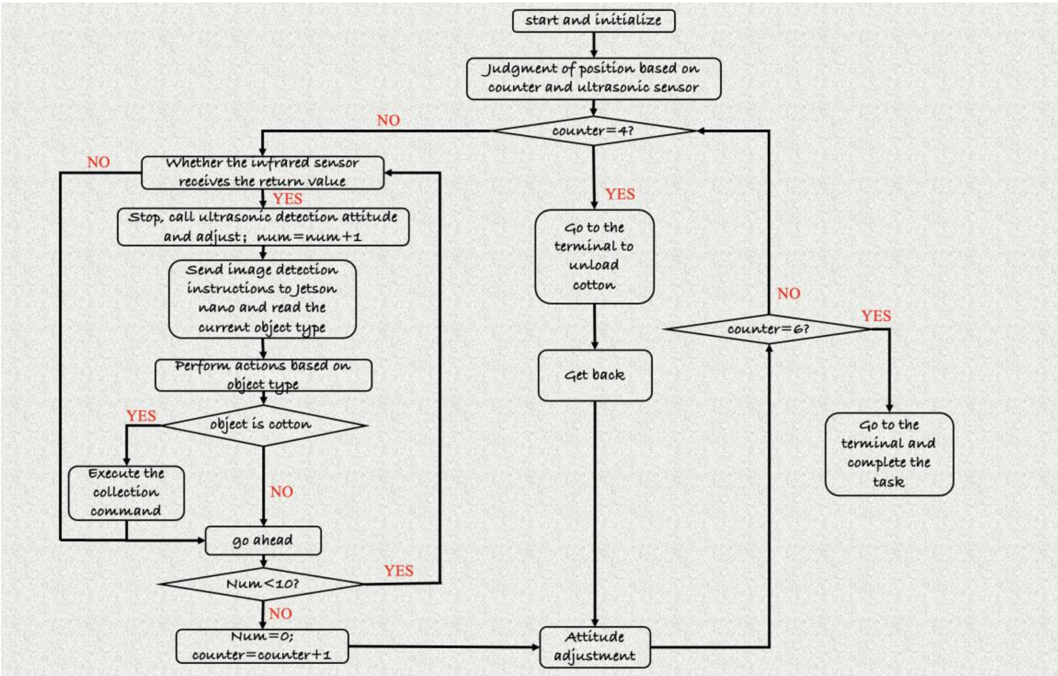


Figure 7-5 Overall Software Workflow

After the robot starts up, it immediately initializes and enters the main program of a specific loop in order. In the main program, the current position of the robot is determined based on the returned values of the ultrasonic sensor and infrared sensor. When the infrared sensor returns a value of 1 (i.e., it receives a return signal), it indicates that the robot is aligned with the row that needs to be operated on. At this point, the robot will call the ultrasonic sensor to detect the distance between the robot and the field board. If there is a certain deviation between the two ends, the robot will adjust the deviation accordingly. After the adjustment is completed, the robot sends a command to Jetson Nano to take pictures and identify the next plant, and Jetson Nano also sends the corresponding object's type to Arduino and performs the corresponding operation. When the robot completes the operation on the corresponding four rows, it will go to the nearest target point to perform the cotton unloading operation. After unloading the cotton, it returns to the starting point of the fifth row and continues the original operation until it completes the fifth and sixth rows and returns to the endpoint. The main process flowchart is shown in Figure 7-3 and the harvesting process flowchart is shown in Figure 7-2.

8 Appropriateness of Tests and Performance Data

8.1 Mapping of Cotton

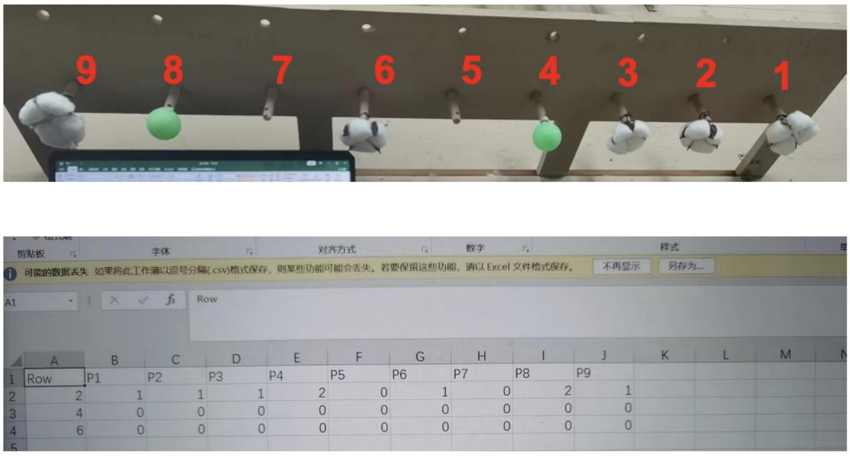
As shown in Figure 8-1, we classified and mapped the targets. As a test, we have not fully followed the rules in the csv output format and we just used the first row as a test. We have marked the cotton, green ball, and empty cotton respectively. The marking rules are as follows:

(1) “0” means empty;;

(2) “1” means mature cotton bolls;

(3) “2” means immature cotton bolls;

As shown in the figure, our classification accuracy rate has reached 100%;



Row	P1	P2	P3	P4	P5	P6	P7	P8	P9
2	1	1	1	2	0	1	0	2	1
4	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0

Figure 8-1 Identification Cartographic Display Diagram

8.2 Collection of Cotton

As shown in Figure 8-2, we tested the effect of cotton collection. Meanwhile, we recorded that the picking time of each row of cotton is roughly 8 seconds.

Figure 8-2 Cotton Picking Effect

As shown in Figure 8-2:

(1) There are 10 cotton plants in the upper and lower heights, each plant contains 3~5 cotton bolls, a total of 40 cotton bolls; the actual picking situation is that 8 cotton bolls were not picked, and 2 cotton bolls were constantly pulled.

(2) The picking success rate exceeds 70%.

9 Achievement of Objectives

At the final presentation, the complete results of the robot are shown in Table 9-1. The cotton harvest was largely in line with our expectations, but we believe it still has the potential to do better.

In addition, we had five human interventions due to cotton blockages and improper positioning of the robot. This is worthy of our reflection and improvement. Although we try our best to optimize the mechanism and procedures to reduce time consumption, the total time spent is still more than ten minutes. Therefore, we choose that the robot has just finished harvesting four rows. Finally, we gave up on picking cotton in the first row (our robot set off from the position in the sixth row). After 9 minutes and 41 seconds of execution, the robot reached the finish area and stopped.

Table 9-1 Complete Scores

Objective	Description	Amount	Score	Subtotal
Harvesting cotton	cotton	147	1	126
	foreign material	21	-1	
Mapping of unripe bolls	unripe boll	12	6	65
	other boll	42	1	
Delivery Score	one robot	1	10	10
Autonomy Score	five human intervention	5	-4	0
Total Score			**201**	
Completion time			**9′41″**	

10 Addition Part --The Iterative Process of Mechanical Design

We have been preparing for the ASABE Robotics Student Design Competition since February .During this process, we also completed several mechanical designs. Although we do not need to provide our mechanical design iteration process, we still showcase them with the hope that we can have a more comprehensive communication with students from around the world.

10.1 The first version--Mechanical Gripper

The first version is a Mechanical Gripper.It controls the contraction and relaxation of the robotic arm through a sliding track.We found it difficult to directly catch cotton, and the harvesting efficiency is too low

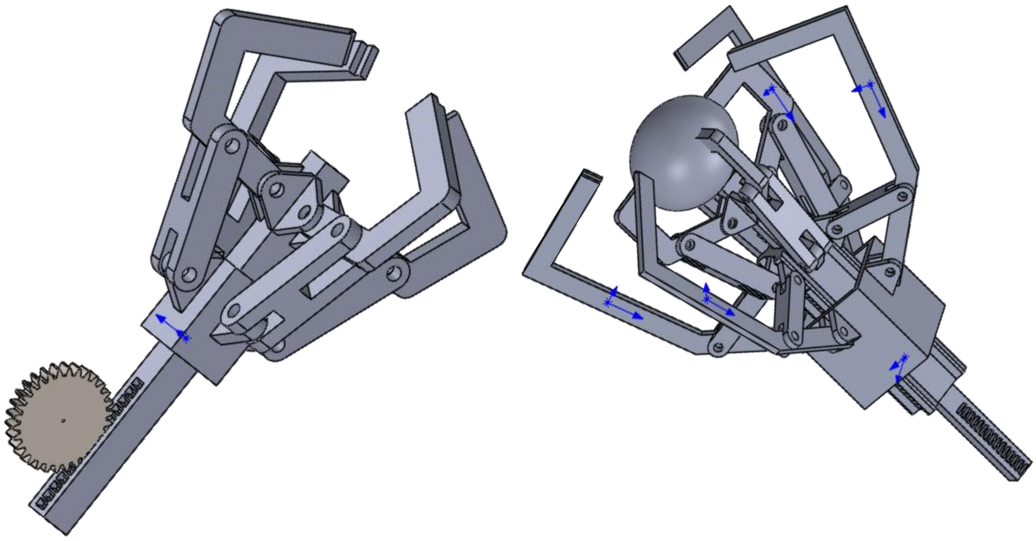


Figure 10-1 Mechanical Gripper

10.2 The second version--Spike Mechanism

The second version is a spike mechanism.It controls the contraction and relaxation of the robotic arm through the gears.We found that it requires high accuracy in the angle and force of grabbing the cotton, and the visual recognition requirements are too high. Additionally, our processor's computing power cannot meet its requirements.

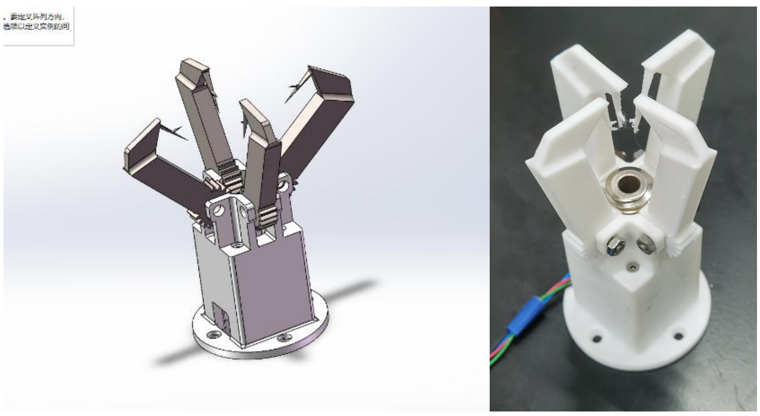


Figure 10-2 Spike Mechanism

10.3 The third version--Crawler Wheel Grabbing Mechanism

The third version is a crawler wheel grabbing mechanism.It rolls up and then picks up the cotton through the protrusion on the track wheel.It has a high harvesting efficiency, but the protrusions of the track do not make good contact with the cotton.

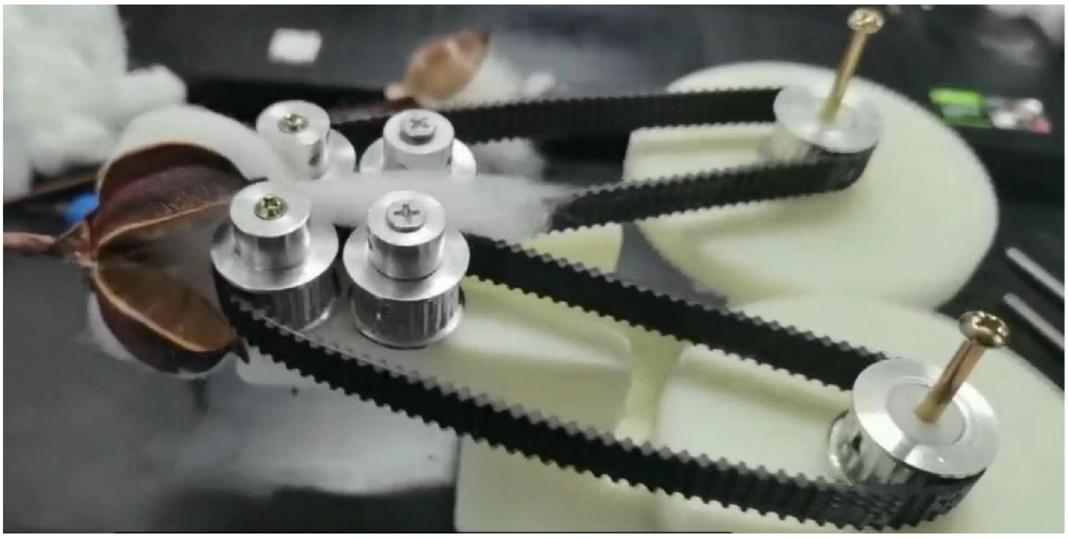


Figure 10-3 Crawler Wheel Grabbing Mechanism

10.4 The fourth version--Barb Gear Combination Mechanism

The fourth version is a barb gear combination mechanism.The symbol ① represents the barb mechanism,which rolls out the cotton by rotating it with a high efficiency.The symbol ② represents the gear mechanism,which rotates to remove the cotton from the barb mechanism with a high efficiency.It is a perfecter design than what we have considered.It is a pity that when we made this version of the mechanism design, we didn't have enough time to replace the original mechanism.

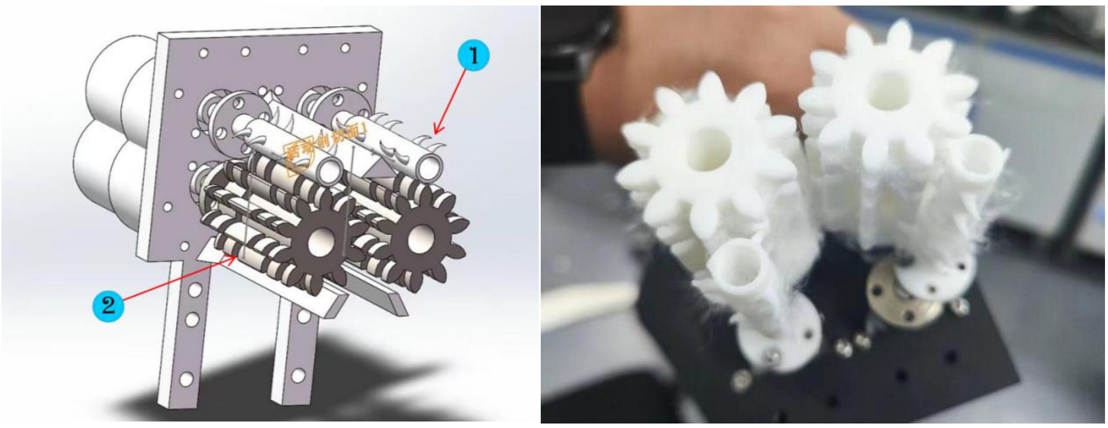


Figure 10-4 Barb Gear Combination Mechanism