2020 ASABE Student Robotics Challenge

Robot Design Report

Division : Standard

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Catalog

1 Team Members

In order to complete the 2021 ASABE student robotics challenge, we formed a five-member team of all sophomore undergraduates, and the specialty of the team members and the tasks we were responsible for in the challenge are shown in Table 1-1.

Table 1-1 Profiles of team members

Name	Specialty	Assigned tasks	Note
Yiyuan Lin	Code writing and debugging C, Python PCB design	·Raspberry Pi code writing and debugging ·Identification ·Robot assembly ·PCB design ·Paper writing	Captain Undergraduate Sophomore
Yuliang Zhou	AutoCAD mechanical drawing SolidWorks 3D modeling Assembly of robot mechanism	·Mechanical structure design ·AutoCAD 2D drawing · SolidWorks 3D modeling ·Robot assembly	Member Undergraduate Sophomore
Daoyuan Jin	Python Code writing and debugging	·Identification ·Raspberry Pi + OpenCV code writing and debugging ·Paper writing	Member Undergraduate Sophomore
Xinyue Sun	Hardware welding Video Production and Editing	·Purchase and reimbursement ·Hardware welding ·Video Production and Editing	Member Undergraduate Sophomore
Yilin Zhang	SolidWorks 3D modeling Assembly of robot mechanism	· SolidWorks 3D modeling ·Robot assembly ·Paper writing	Member Undergraduate Sophomore

2 Establishment of Need and Benefit to Agriculture

2.1 Strawberry Plant Overview

Strawberry is a perennial herb with a plant height of about 30 cm and a shallow root system, suitable for growth in a loose and fertile soil with good drainage. The leaves are dark green, oval in shape, and dark green if the plant is regularly fertilized, and it performs physiological functions of photosynthesis, respiration, and storage.

Strawberries can flower and bear fruit all year round. As shown in Figure 2-1, each strawberry plant generally has 2-3 inflorescences, each inflorescence bears 3-30 flowers and 10-40 small fruits.

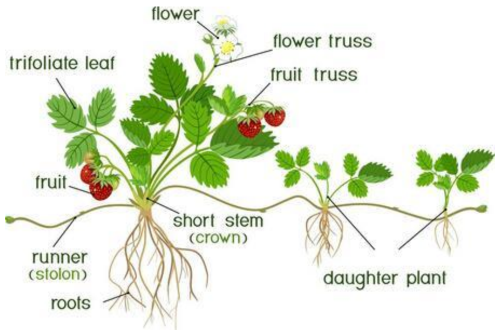


Figure 2-1 Strawberry

2.2 Why to Find Yellow Leaves

As shown in Figure 2-2, due to large changes in ambient temperature or trace element deficiency, the plant can wither and the leaves turn yellow. The loss of photosynthesis ability of the yellow leaves will affect the normal growth of the plant, which in turn will lead to yield reduction, thus causing economic losses, which need to be identified and removed in time.

Figure 2-2 Yellow leaves of strawberry

2.3 Why to Remove White Flowers

As shown in Figure 2-3, These small fruits have no harvesting value. Without being removed, unfair competition for limited nutrients between the fruits that are on the same plant will occur. Therefore, in strawberry cultivation, flower thinning can reduce the nutrient consumption, so that the retained flowers are well developed, the fruit is neatly set, and the appearance and quality of the fruit can be improved accordingly. In order to increase the yield and prevent premature decay, while making the ripening period concentrated and saving harvesting labor.

Figure 2-3 White flower of strawberry

2.4 Design Meaning

① Identify and count the yellow leaves of strawberry plants to reduce the impact of yellow leaves that have lost their light and ability on the plants, thus promoting the healthy growth of plants.

② Identify the white flowers of strawberry plants and count them for agricultural transplanting, so as to reduce fruit competition and nutritional loss of the same plant, make the retained flowers develop well and fruit set neatly, and improve the appearance and quality of the fruit accordingly, so as to achieve the purpose of increasing yield and preventing premature decay, and at the same time make the maturity period concentrated and save harvesting labor.

③ Reduce agricultural labor consumption and lower agricultural production costs.

3 Definition of Design Objectives and Criteria

The robot to be designed for this competition should have the ability to recognize the white and yellow leaves of strawberry plants and 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 Identify white flowers and yellow leaves on each strawberry plant.

③ Transfer detection results of individual plants to a server program for scoring and field map generation.

④ Minimize the weight of the robot and increase the contact area to reduce the pressure.

⑤ No damage to the plant.

⑥ No human intervention to the robot.

⑦ Have a start button that judges can use to initiate a competition trial and an emergency stop button to fully shut down the entire system.

In the design of robot, we are committed to assure better performance, stronger environmental adaptability, and expandability with more development prospects.

4 Approach and Originality

4.1 Approach

4.1.1 Hardware

For farm work machinery, the pressure of the robot on the farm is proportional to the degree of damage to the farm by the robot. Smaller pressure is conducive to actual production and application. Therefore, we adopt a crawler structure with stepper motors for driving to obtain the maximum contact area under the same quality, thereby reducing the pressure of the vehicle on the ground as much as possible. In order to stretch the robot from a smaller size to a higher height to obtain the largest possible field of view with higher adjustability, we used a mechanical structure with a rod group and slide rails, allowing the mechanism to be fully expanded, and a wide-angle camera to obtain a wider field of view. We use a lithium battery with an output voltage of 16V to power the Raspberry Pi through the UBEC module, and a voltage regulator module to power and control various electronic components with different operating voltages.

4.1.2 Software

In actual production, most agricultural operation robots can only achieve unilateral operation, which reduces the operation efficiency and increases the time cost. We planned to use a 4th generation Raspberry Pi with 2GB RAM as not only the processor but also the main controller. The Raspberry Pi is connected to all electronic devices on the robot through voltage regulator modules and USB interfaces. For recognition and control tasks, the Raspberry Pi handles them separately through its multi-threaded processing capability and our robot has bilateral simultaneous recognition capability. The Raspberry Pi extends the combined linkage mechanism through the servo and receives the signals returned by the bilateral planks through the infrared sensors for tracing. Finally, the Raspberry Pi transmits the recognition result to a dedicated server computer through the wireless transmission module.

4.1.3 Conclusion of Approach

Overall, our robot controls all the electronic components on the robot through the Raspberry Pi. The Raspberry Pi drives stepper motors and servo, processes signals from infrared sensors through GPIO pins for tracing, connects to camera through USB port to process images captured by the camera, and uploads recognition results to a dedicated server computer through a wireless transmission module.

4.2 Originality

4.2.1 Innovative Linkage Design

We use the combination mechanism of slider and linkage to realize the full unfolding of double cameras bracket and create the development condition for double sides identification. And the linkage mechanism has strong scalability, which can reach different unfolding results by adding nodes, connecting rods or linkage structures to meet a variety of needs, and can also add end-effectors at the end of the linkage to achieve more functions.

4.2.2 Lower Pressure

We adopt the crawler trolley structure and make the optimal design for the actual production situation of field operation by calculating and selecting the appropriate size of active wheels, tensioning wheels and load-bearing wheels and determining the optimal spacing to share the pressure to the maximum extent and reduce the impact on soil compaction.

4.2.3 Infrared-Sensor Tracking

Since we make the robot travel between the board where the strawberry plants were placed and the board as the boundary of the field, we only need to install the infrared sensor at a suitable height (That is, slightly below the thickness of the board on which the strawberry plants are placed, as shown in Figure 4-1), adjust the sensitivity of the signal received by the infrared sensor, and keep the robot moving in a straight line in the desired area by making reasonable use of the differential speed rotation of the stepper motor through the signal measured by the infrared sensor.

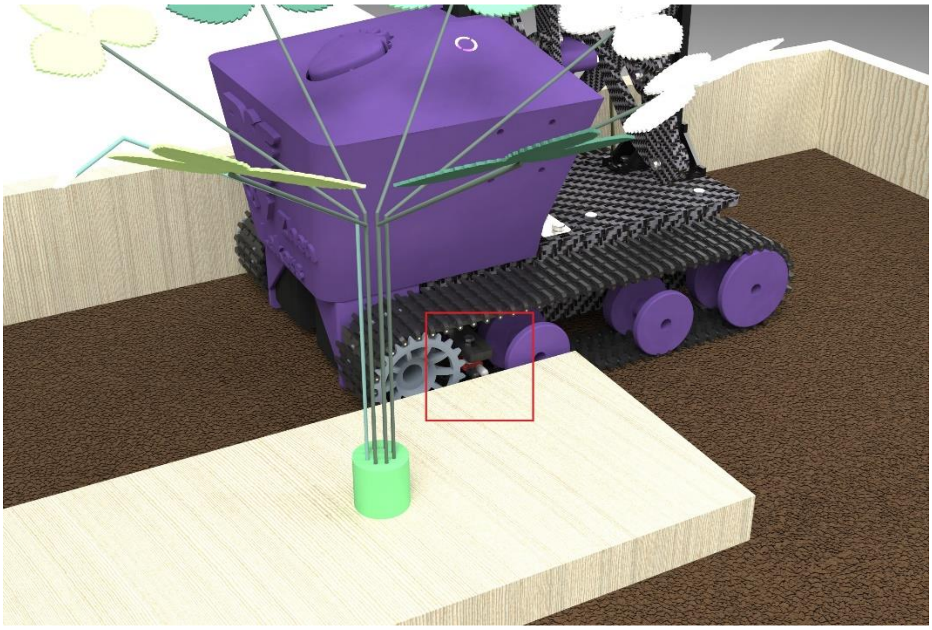


Figure 4-1 Installation height of the infrared sensor

4.2.4 Supplemental Light Source

By increasing the fill light band, we make the recognition conditions within the controllable range, eliminate the influence caused by different environmental backgrounds, increase the contrast between the recognition target and the background, and make the robot have better self-adaptability.

4.2.5 Multi-threaded Process

We use Raspberry Pi as both processor and control component, and all electronic devices of the robot are controlled through the Raspberry Pi. Calling Python's multi-process module, 3 processes of Raspberry Pi run simultaneously, thus giving higher performance and increasing working speed. The tasks of motor and servo rotation, simultaneous image processing recognition of cameras on both sides and wireless transmission are realized.

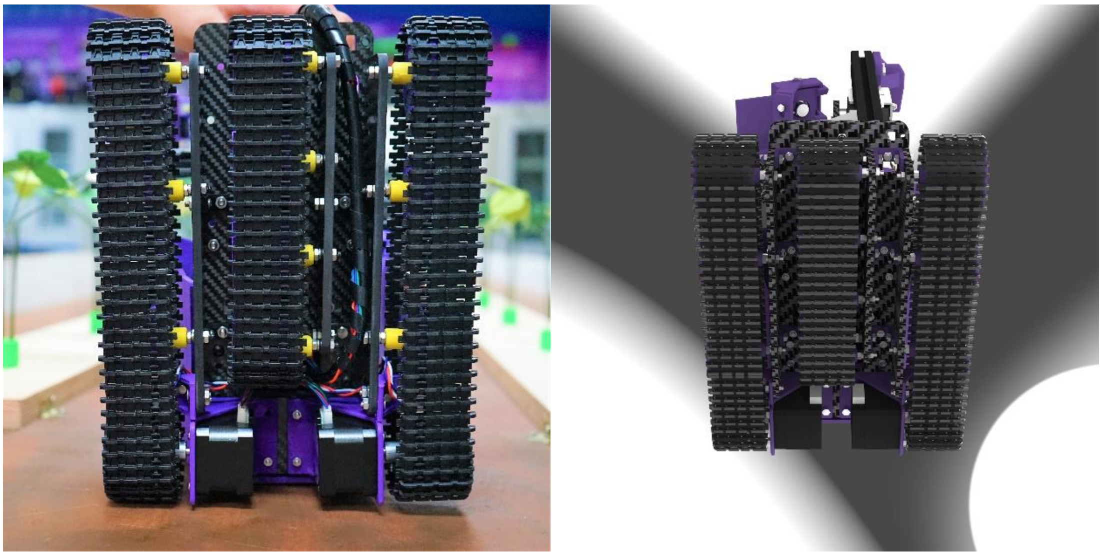
4.2.6 Remote Emergency Brake

Through the wireless transmission module and Bluetooth module of Raspberry Pi, we designed several remote emergency braking solutions. Although there are already both start switch and emergency brake switch on the robot, considering that there are certain safety hazards of actually approaching the brake when an unpredictable emergency occurs, we made a remote emergency brake switch, which is connected to the Bluetooth module, thus controlling the operation of the Raspberry Pi. In addition, using WIFI wireless communication technology, we can access the graphical interface of the Raspberry Pi for operation. Since all the robot components are controlled by the Raspberry Pi, we can stop the operation of the Raspberry Pi at any moment and thus stop the robot operation. Of course, this does not allow the robot to cut off the power supply system, so we designed an emergency brake switch on the robot to directly cut off the power supply.

5 Hardware Description of the Mechanical Structure

5.1 Crawler Structure

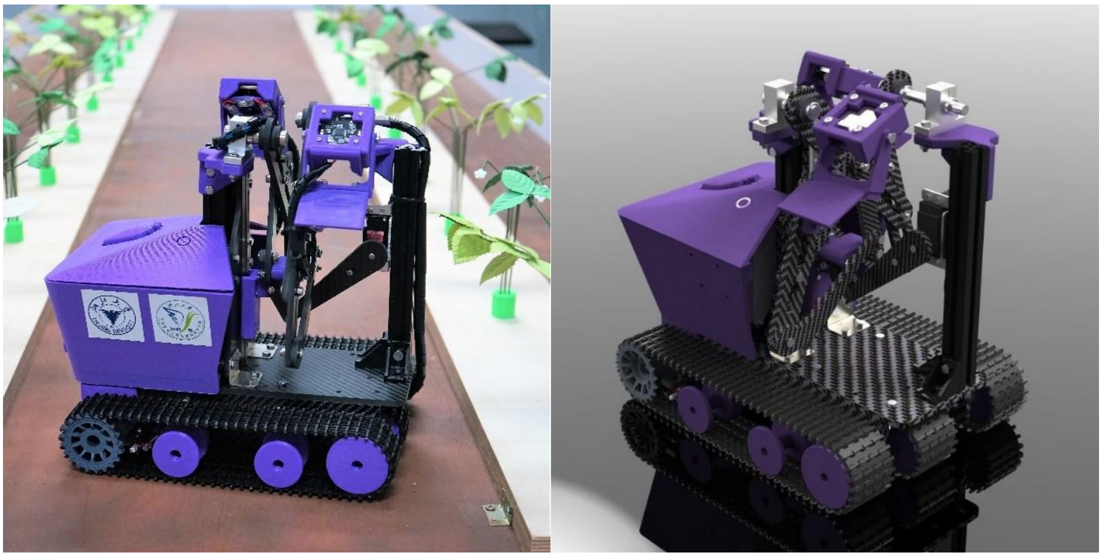
In order to reduce the impact on soil compaction and to allow the robot to adapt to a wider range of road environments, we designed a tracked travel mechanism, as shown in Figure 5-1.



(a) Physical picture (b) Model picture in SolidWorks

Figure 5-1 Crawler chassis

The outer two tracks are long tracks with a ground length of 223.5 mm and a width of 45 mm, equipped with one active wheel, one tensioning wheel and two load-bearing wheels. The middle track is a short track with a ground length of 160 mm and a width of 45 mm, and is equipped with four load-bearing wheels. By reviewing the relevant literature, we calculated the radius and spacing of the active wheel, tensioner wheel and load-bearing wheel. Under the size limitation, we selected the optimal size and spacing, as shown in Figure 5-2 and Table 5-1.



(a) Photo of the robot (b) Robot model in SolidWorks

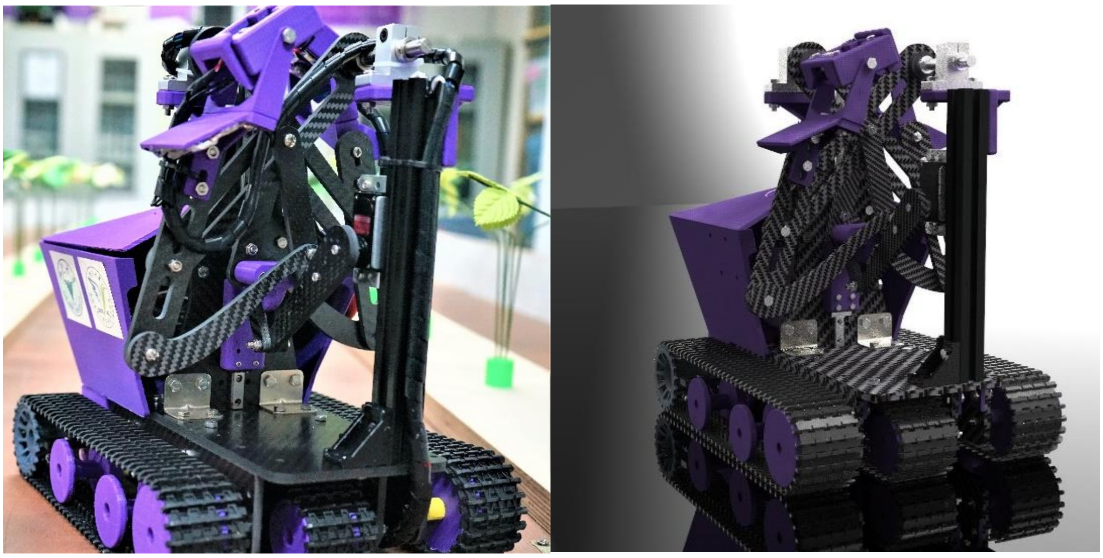
Figure 5-2 Photo of the robot(a) and the robot model in SolidWorks(b)

Table 5-1 Radius of the three types of wheels

Type of wheel	Radius
Active wheel	25.65 mm
Tensioning wheel	26.65 mm
Load-bearing wheel	20.00 mm

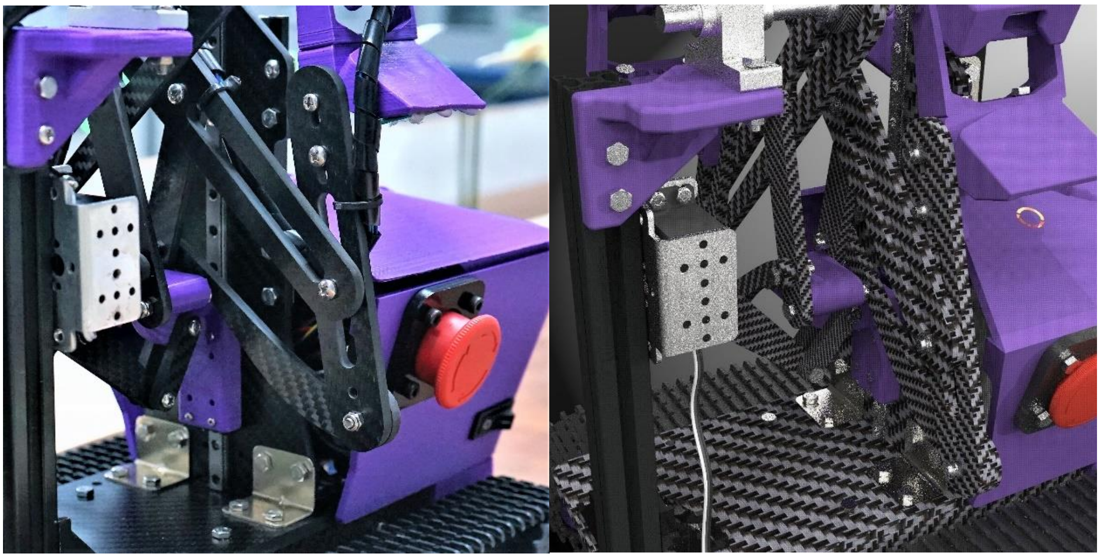
5.2 Expanded Mechanical Structure

To simplify the actuator, we use a slide rail and a single-degree-of-freedom extension mechanism with multiple links to extend the camera for identification. The multi-stage linkage is articulated by screws and lock nuts (as shown in Figure 5-3), connected to the slide rail by slider connectors (as shown in Figure 5-4), and uses bearings at some of the connections to reduce frictional resistance, and rotates, lifts, and extends under the drive of the servo. As shown in Figure 5-5 and Figure 5-6, with the rational design of 4 connecting rods on each side (8 in total on both sides), we achieved to expand the robot from the initial size of 300 mm × 209.2 mm × 292.5 mm to 300 mm × 440 mm × 528 mm.



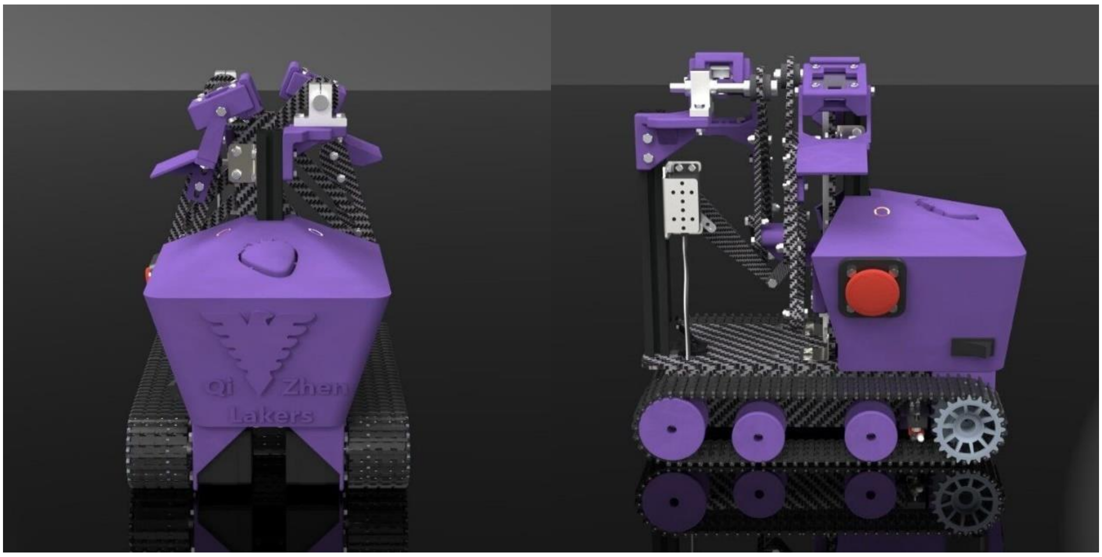
(a) Physical picture (b) Model picture

Figure 5-3 Connection between multi-stage connecting rods



(a) Physical picture (b) Model picture

Figure 5-4 Connection between multi-stage connecting rod and slide rail

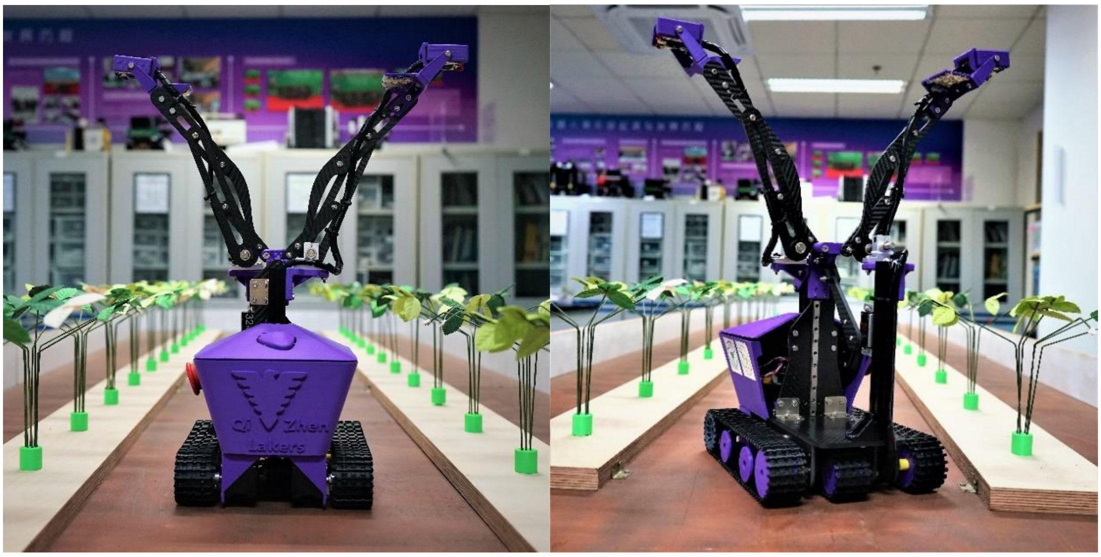


(a) Model picture of front view (b) Model picture of side view

(c) Physical picture of front view (d) Physical picture of side view

Figure 5-5 Front view of the connecting rod before expansion

(a) Model picture of front view (b) Model picture of rear view

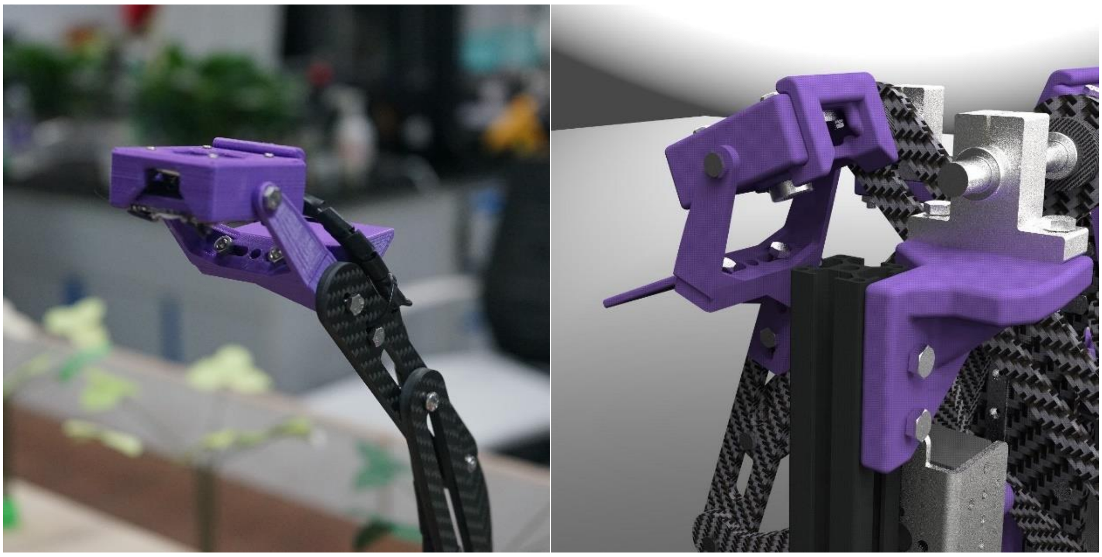


(c) Physical picture of front view (d) Physical picture of rear view

Figure 5-6 Views of the connecting rod after expansion

5.3Adjustable Field of View

In order to facilitate the adjustment of the camera view, we designed a camera connector adjustable in angle, as shown in Figure 5-7.



(a) Physical picture (b) Model picture

Figure 5-7 Camera connector

6 Hardware Description of the Main Electronic Component

6.1 Raspberry Pi

We chose Raspberry Pi 4B as the processor to control the whole robot work. It is an ARM based satellite computer motherboard with SD/MicroSD card as memory drive, USB and Ethernet ports around the card motherboard, TV output port for video analog signal and HDMI HD video output port. With a 64-bit quad-core processor running at 1.5Ghz, dual displays supporting up to 4K resolution refreshed at 60fps, and up to 4GB RAM, performance is significantly improved in terms of processor speed, multimedia and memory with desktop performance comparable to entry-level x86 PC systems.

6.2 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.

6.3 Servo

We chose MG996 32 Kg black digital servo. This digital servo has fast response, precise angle, gears of aluminum oxide, double ball bearings with no-load speed of 0.18 s/60° and blocking torque of 30.8 Kg/cm under operating voltage of 6 V, which is enough to drive the servo to extend the identification mechanism.

In addition, due to the small internal resistance of this servo, no jitter rudder and blocking rotation protection function, it can completely get rid of the phenomenon of jitter rudder and blocking rotation burnout of the servo in operation.

6.4 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.

6.5 Infrared Sensor

Infrared transmitter tube constantly emits infrared, when the emitted infrared is not reflected back or is reflected back but the intensity is not large enough, the infrared receiver tube has been in the off state, at this time the TTL output of the module is high, the corresponding indication diode has been in the off state; when the detected object appears in the detection range, the infrared is reflected back and the intensity is large enough, the infrared receiver tube conducts, at this time The TTL output of the module is low and the indicator diode is lit for testing. The TTL output of the module is low and the diode is lit for testing.

6.6 Circuit Board

We designed custom PCB board for connecting the Raspberry Pi and other electronic components, the connection between the Raspberry Pi and electronic components is shown in Figure 6-1. (In order to show the connection between electronic components visually and clearly, only an abbreviated connection diagram is made here, not the actual connection situation)

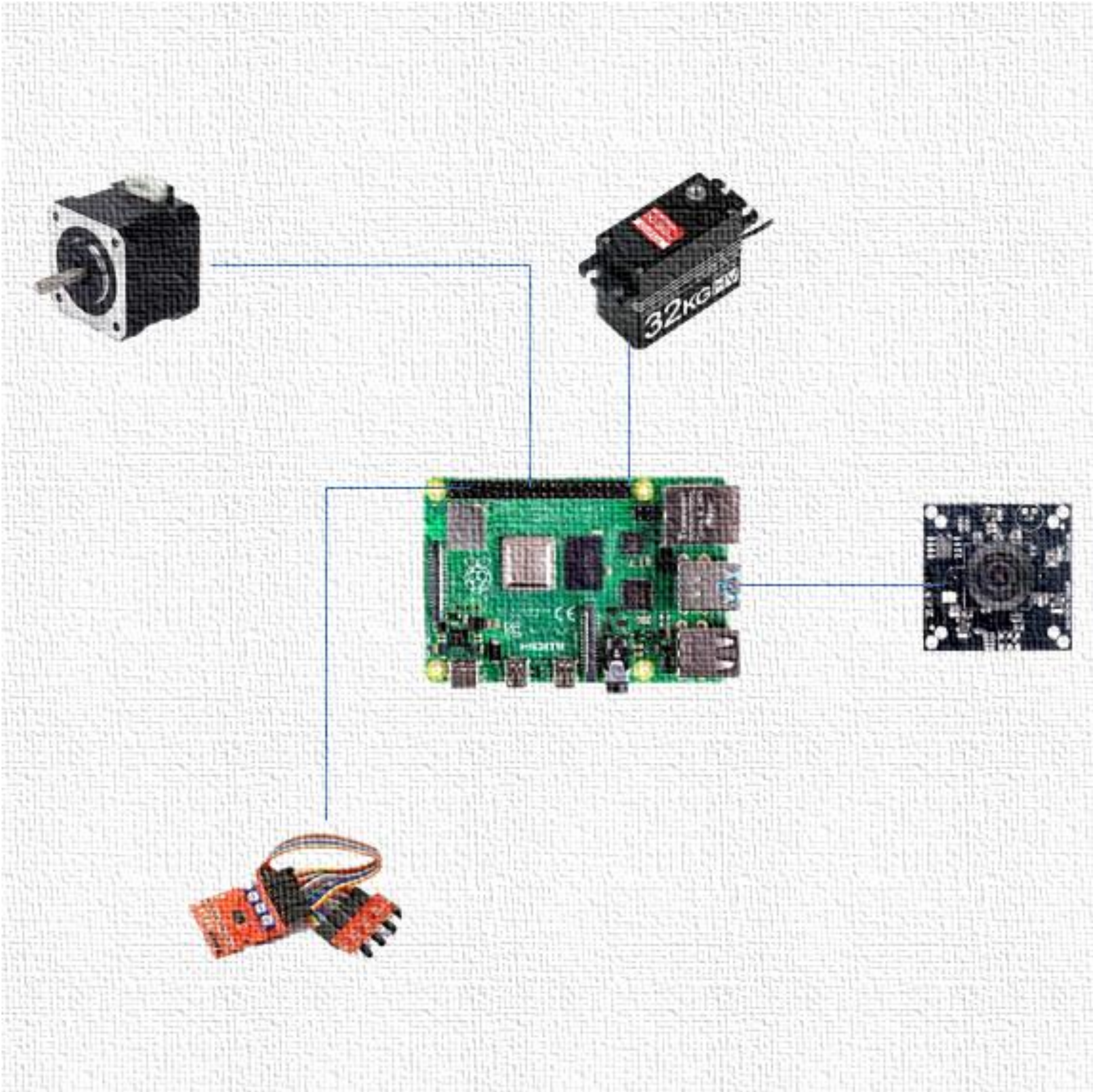


Figure 6-1 Schematic diagram of the hardware connection

The electronic component we used is shown in Table 6-1

Table 6-1 Main electronic components list

The name of the hardware	Type	Appearance	Amount
Raspberry Pi	Raspberry Pi 4B		1
Stepper motor	42HB34-401A		2
Servo	MG996		1
Camera	720P-1280×720-mjpg/30 fps		2
Infrared sensor	HW-096-A		2
Circuit board	Designed by ourselves		1

7 Software Overview and Logic Flowchart

7.1 Main Program Design

The logic of the main program for robot operation is shown in Figure 7-1.

When the power is turned on, Raspberry Pi starts the corresponding multi-threaded program to determine the location of the site through the infrared sensor and calls the corresponding camera for the identification task, while the robot tracks through the infrared sensor. When the Raspberry Pi controls the camera to identify the plant base, it identifies the strawberry plants belonging to the base and flashes the LEDs of corresponding color to warn the presence of yellow leaves or white flowers. After each plant is identified, the information about leaves and flowers of the plant is immediately transferred to the GUI program. For plants that are not identified, we default them as healthy plants and record the number of yellow leaves and white flowers as 0 temporarily, and overwrite the result if yellow leaves and white flowers are identified later. After identifying all twelve plants, the real strawberry plant located at the end of the field is identified, and all tasks are completed and the robot stops running after the identification is finished.

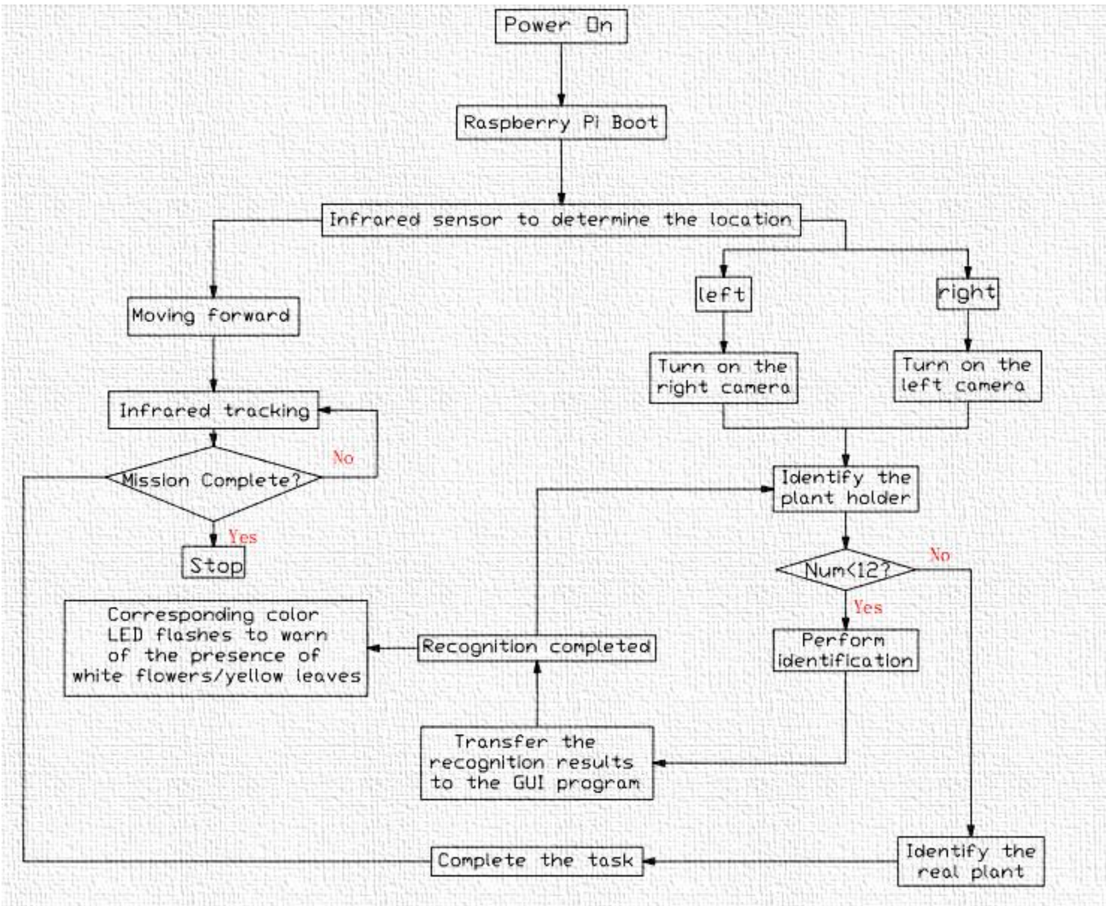


figure 7-1 Logic flowchart of main program

7.2 Tracking Design and Walking Route Map

As shown in Figure 7-2, the robot sends and receives the infrared signal reflected back from the wooden board through two infrared sensors installed between the active and load-bearing wheels on the outer track to determine the position of the site it is in, and adjusts its direction by controlling the differential rotation of stepper motors through Raspberry Pi to ensure that the robot can achieve a straight line in the site along the path as shown in Figure 7-3 to provide the best position for identification.

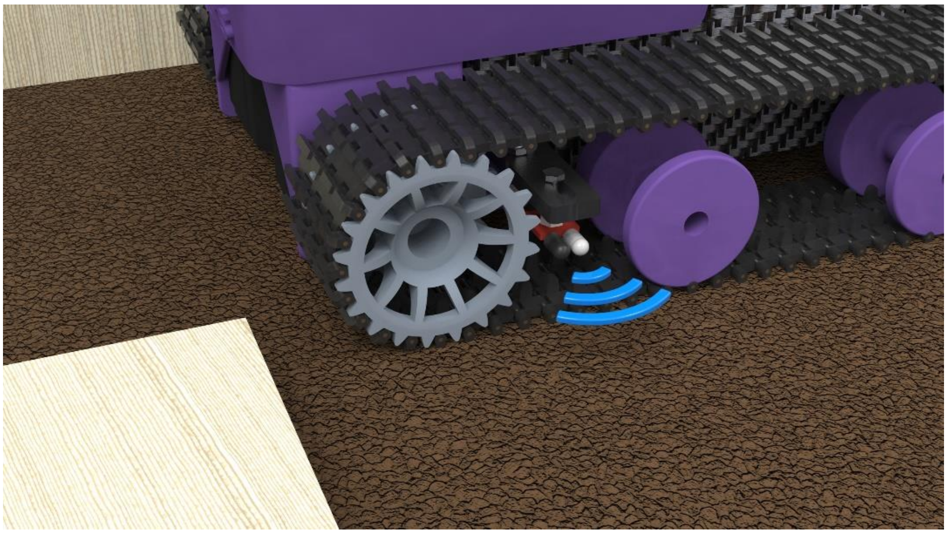


Figure 7-2 Working principle of infrared sensor

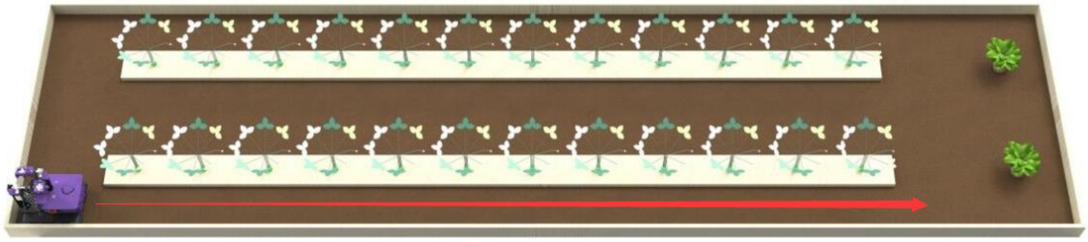


Figure 7-3 The route of the robot

7.3 Machine Vision

7.3.1 Holder Identification

After the robot starts to run, it first identifies the holder. We use the color and shape characteristics of the holder to match the data obtained from the camera, and when the camera moves to the top of the holder, we save the image acquired by the camera instantly for subsequent processing, and get the coordinate information of the holder center.

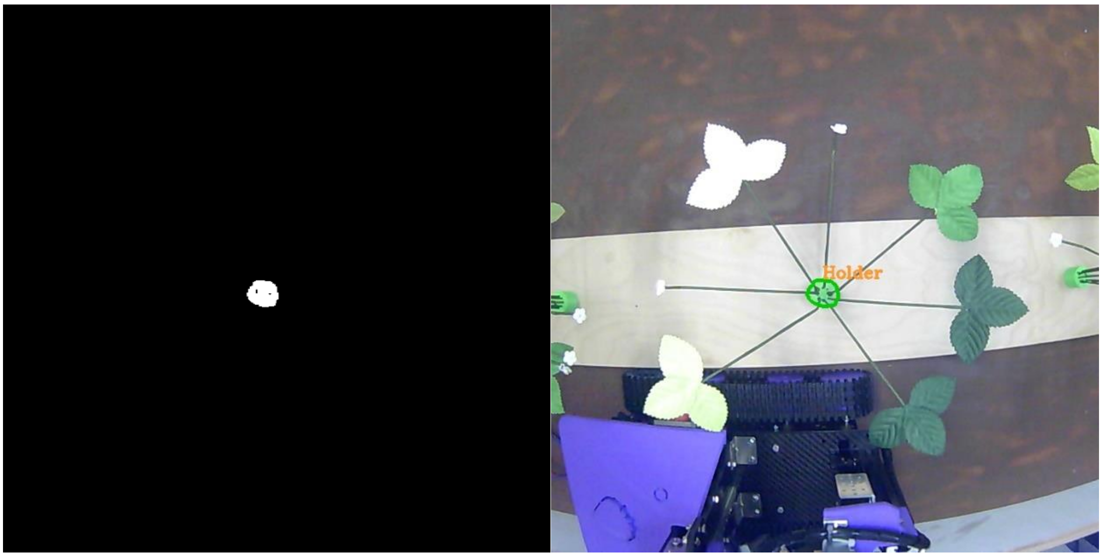


Figure 7-4 Binarization of holder identification

7.3.2 Leaf Identification

After getting the image directly above the plant, the colors in the image are extracted using the green, yellow and white thresholds, respectively. The filtered images of each color channel are filtered to obtain images with smoother borders, and the area and shape parameters of the continuous areas in them are calculated, while the noisy parts with obviously small areas or narrow shapes are filtered. The image of each color channel is processed as mentioned above to get a grayscale image containing only leaves, and the leaves of each color in it are counted in order to store the number of corresponding color leaves.

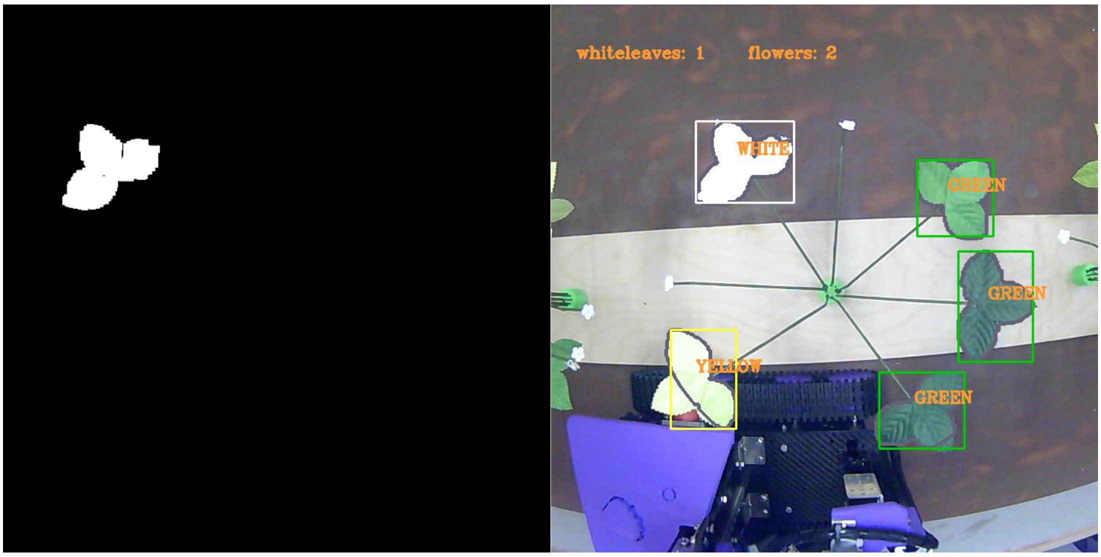


Figure 7-5 Binarization of leaf identification

7.3.3 Flower Identification

In particular, the results after the white threshold extraction in the previous session are re-processed with filtering and area calculation, and graphical matching is added to obtain the identification results of white flowers.

Figure 7-6 Flower identification

7.3.4 Stem Identification

Similarly, we use the characteristic values of stem color to filter specific locations in the image to obtain a grayscale image of the stems for counting the stems.

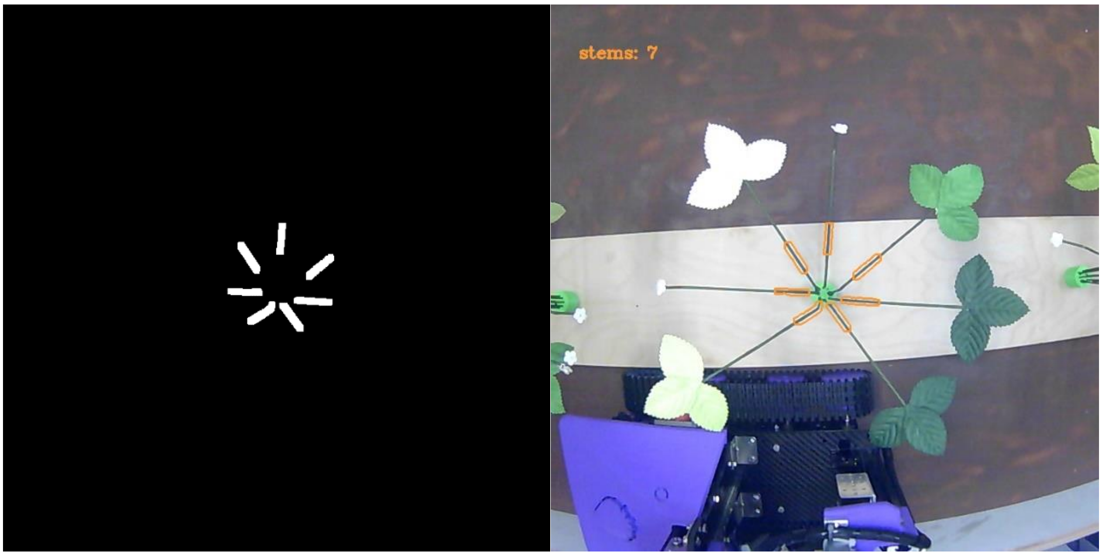


Figure 7-7 Stem identification

7.3.5 Auxiliary Methods for Identification

① LED supplementary lighting

We installed LEDs to uniformly illuminate the strawberry plant at the position near the camera to eliminate the effect on identification and increase the contrast between the strawberry leaves, white flowers and the background wood panel from ambient light difference to improve the identification accuracy.

② Region of interests

After getting the result of holder detection, we take the holder as the center of circle and combine the dimensions of strawberry plant and base to get the radius, and build multiple ROIs for the locations where stems, flowers and leaves may appear in the camera field of view to narrow down the identification range. The introduction of ROIs reduces the influence of irrelevant contents on the identification and help speed up the program operation.

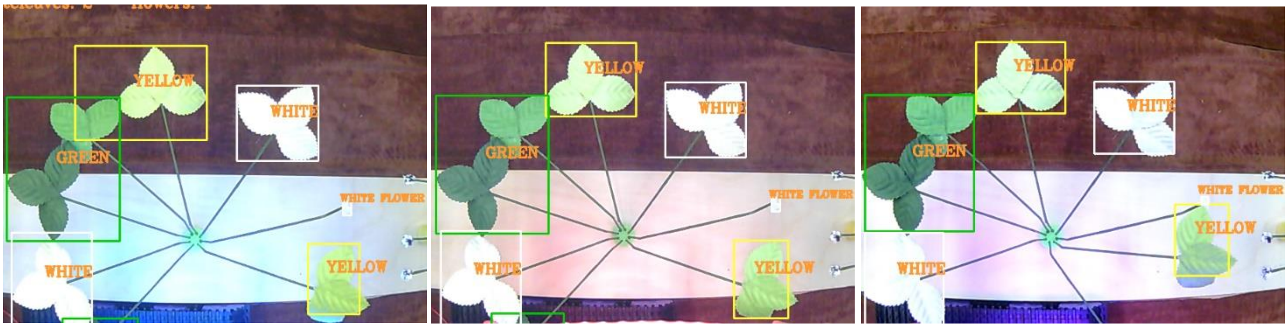
③ Stems Identification

In fact, the results of the analysis of flowers and leaves identification were enough to complete the task of the competition. Therefore, we use the obtained stems data to check the results of flowers and leaves identification. If the two results do not match, a new identification is required.

7.3.6 Appropriateness of Tests and Performance Data

Considering that in actual agricultural production strawberries are mostly grown in greenhouses, and the farmer will use different fill light measures according to the actual situation in order to improve the yield, we adjusted our recognition program to the extent where it can adapt to a variety of common greenhouse fill light ambient light sources. As shown in Figures 7-8, we simulated four different ambient light sources: red light, blue-violet light, red light + blue-violet light, and white fluorescent light. Under the condition that the robot itself is equipped with white LED light sources for supplemental lighting, we adjusted the appropriate parameters and collected sufficient data sets for template matching of white flowers. Finally, the accuracy of recognition results in the three environments is shown in Table 7-1.

Also, demonstrated in Figures 7-8, the impact of the ambient light source on the leaves and flowers is effectively reduced due to the supplemental lighting measures taken by the robot itself when identifying the strawberry plants.



Testing under blue-violet light conditions   Testing under red light conditions   Testing under blue-violet & red light conditions

Figure 7-8 Recognition results under different ambient light sources

Table 7-1 Recognition accuracy under different ambient light sources

Environmental light sources	**Recognition accuracy**	**Number of tests**	**Overall recognition accuracy**
White fluorescent lamp	98.5%	>200	89.8%
Red light	87.5%	100	
Blue violet light	88.1%	100	
Red light & blue violet light	76.4%	100	

It should be noted that the accuracy of recognition results here is calculated as the ratio of the total number of correctly recognized white flowers and yellow leaves to the total number of all white flowers and yellow leaves. In addition, considering that the robot was designed with the primary goal of completing the competition, we assigned a higher weight to the white fluorescent environment, and the parameters of the recognition program were eventually adjusted to the optimal parameters based on the weights, resulting in the highest total recognition accuracy.

In order to improve the overall speed and fluency of the robot, we used multi-threaded processing for recognition. Thread 1 is used to identify the plant base to determine the plant location and take pictures to save them in the memory of the Raspberry Pi. Thread 2 is used to process the images taken in process 1 (Thread 3 is used to control the robot's advancement and expansion). This design makes our robot run much faster and smoother, with thread 1 achieving a frame rate of 30 frames per second on the Raspberry Pi 4B and thread 2 processing images at 0.25 ms per image. The robot does not need to stop while moving forward, which reduces the occurrence of linkage wobble and greatly improves the overall speed and fluency.

7.3.7 Logic Flowchart of Identification

In summary, the Logic Flowchart of our machine vision processing plant information is shown in Figure 7-9.

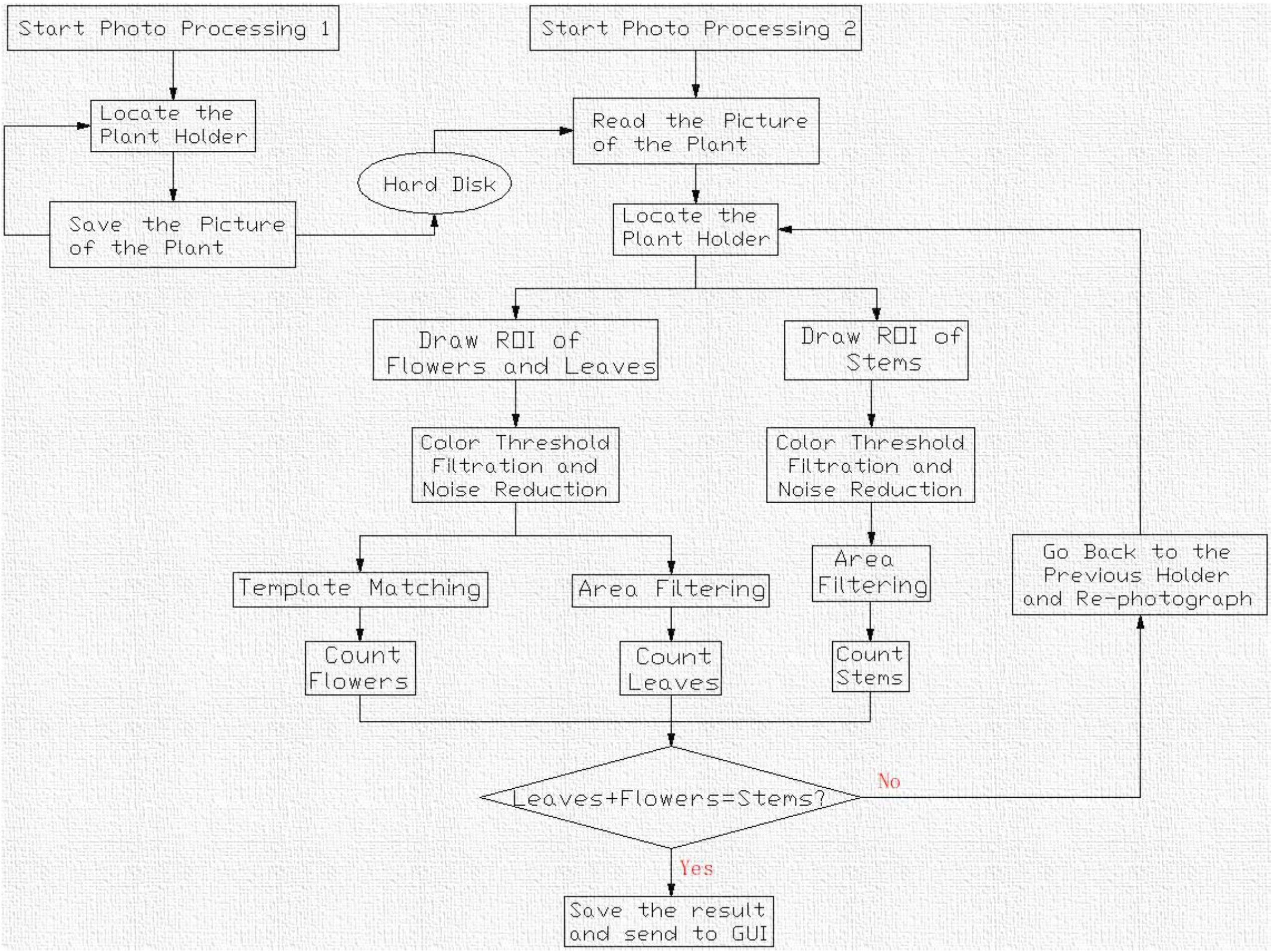


Figure 7-9 Logic flowchart of identification

8 Robot parameters

8.1 Weight of Robot

As shown in Figure 8-1, the robot is weighed using an electronic scale, and the weight of the robot is M = 2.90 kg.

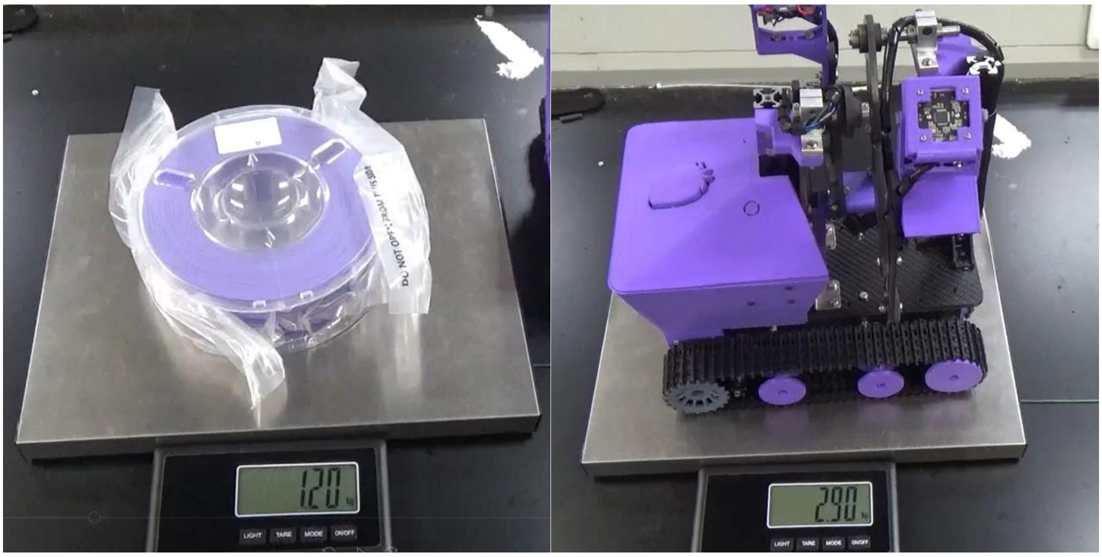


Figure 8-1 Robot weighing scene

8.2 The Contact Area of the Robot with the Ground

Since the length of the outer two long track tracks is l_1=223.5 mm and the width is w_1=45 mm, and the length of the inner measured short tracks is l_2=160mm and the width is w_2=45 mm, the contact area between the robot and the ground can be approximated as

$$S \approx 2l_1w_1 + l_2w_2$$
$$= 2 \times 223.5 \times 45 + 160 \times 45$$
$$= 27315\ mm^2$$
$$= 0.027\ m^2$$

8.3 The Pressure of the Robot on the Ground

From the data in 8.1 and 8.2 above, the pressure of the robot on the ground can be calculated as

$$P = \frac{Mg}{S}$$
$$= 1040.45\ Pa$$

g - gravity acceleration, here take g = 9.8 kg/N

9 Parts List and Cost Analysis

As shown in Table 9-1, the total cost of our robot was $281.4. As shown in Table 9-2, the total cost of computational devices to be integrated with our robot was $35.

Table 9-1 Total cost

Material	Unit Price (CNY)	Amount	Total price (CNY)
Carbon fiber	450	1	450
Circuit board	8	1	8
Raspberry Pi 4B	226.59	1	226.59
Stepper motor	30	2	60
Motor drive	12	2	24
MG996 servo	280	1	280
Camera	75	2	150
Infrared sensor	2.5	2	5
Aluminum profiles	14	2	28
3D printing consumables	/	/	85
Crawler	6	3	18
Screws of different size(M3&M4)	/	134	2
Nuts of different size(M3&M4)	/	89	2
Lock nuts of M4	/	26	1.5
Slider	20	2	40
Rail	6	1	6
Angle iron	0.3	9	2.7
Bearing	3	10	30
Bearing support	3	2	6
Bracket for servo	2	1	2
Positioning pins	2.5	2	5
Active wheel	2	2	4
Switch and wires	/	/	10
Sum			**1445.79 ($224)**

Table 9-2 Computational devices

Material	Unit Price (CNY)	Amount	Total price (CNY)
Raspberry Pi 4B	226.59	1	**226.59 ($35)**

As shown in Table 9-2, the only computational device we used was the Raspberry Pi 4B, which cost $35, far less than the $100 limit set by the organizers.

10 Achievement of Objectives and Reflection

10.1 Achievement of Objectives

As shown in Table 10-1, based on our design, our robot is able to perform all the tasks perfectly.

Table 10-1 Achievement of Objectives

Objective	Amount	Score	Subtotal
Correct identification and mapping white flowers	16	3	48
Correct identification and mapping yellow leaves	11	1	11
Mapping the entire plant correctly	12	3	36
Mapping the entire row correctly	1	5	5
Have a navigation function without guidelines	/	/	√
Plants get damaged	0	0	0
Transmits detection and counting results from the robot to a dedicated server computer.	/	/	√
Not any human intervention occurs	/	/	10(bonus)
Have a start button that judges can use to initiate a competition trial and an emergency stop button to fully shut down the entire system.	/	/	√
Total			**110**
Completion time			**00:25**

10.2 Reflection

There is no denying that our design still has a lot of immaturity, and we are constantly reflecting on our design and doing some thinking.

10.2.1 Rotation Speed

As shown in Figure 10-1, the camera extension mechanism unfolds through a ninety-degree right angle, where a great torque is required from the servo and a certain initial speed is needed to turn smoothly to the desired angle.

By adjusting the duty cycle of PWM wave to achieve flexible control of the servo, instead of the original discrete angle rotation. Furthermore, we can add electronic components such as pressure sensors to get the current force of the mechanical structure and adjust the rotation speed of the servo in real time, so as to extend the service life of each component.

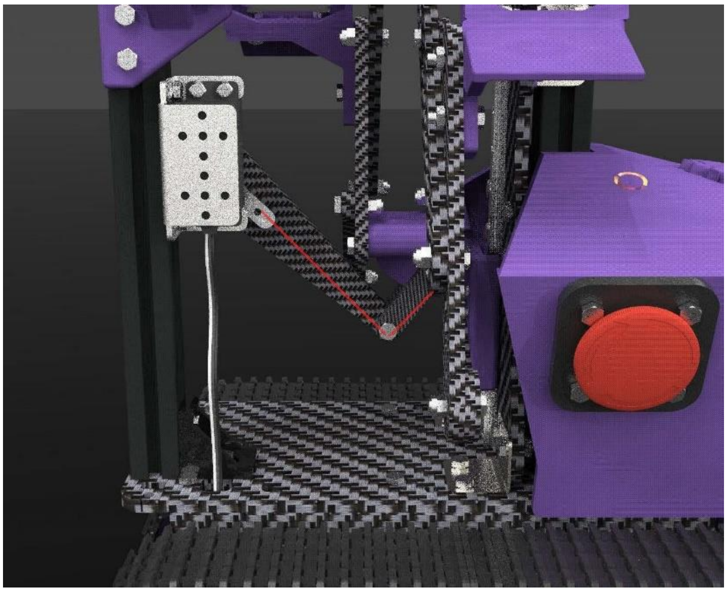


Figure 10-1 The right angle passed during the rotation

10.2.2 Exposed Components

Some of the electronic components of the robot are exposed on the outside and cannot cope with weather conditions such as rain. Although strawberries are generally grown in agricultural greenhouses, it is still necessary to take into consideration humidity and the influence of other factors.

Using 3D printed parts to cover the electronic devices reasonably can prevent the circuit from moisture performance changes, but also effectively prevent the metal from rusting and prolong the service life. By designing the hollow structure, the wires can be placed inside the mechanical structure.

10.2.3 Rods Connection

Due to size restrictions and other reasons, rod is screw-connected, yet to be optimized.

We hope to add bearings at the connection to reduce friction and protect the parts, and a servo with less torque can be selected to save energy and cost.

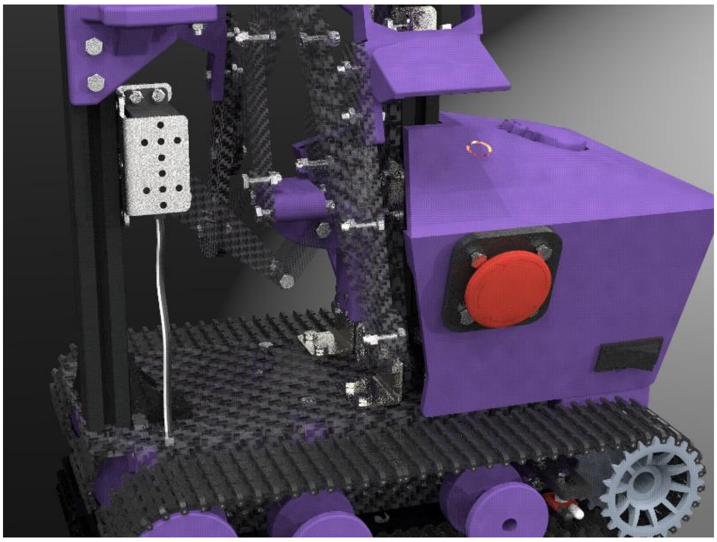


Figure 10-2 Rods and screws(perspective view)

10.2.4 Manual Adjustment of Camera

Although the camera connector of our device is equipped with the function of view adjustment, the actual application is yet in need of a more intelligent and automatic adjustment method.

Small servos can be added to the camera connector to help adjust the field of view automatically.

10.2.5 Multi-Linkage Connection

Although we control the gap of rod-rod connection and rod- pedestal connection to be as small as possible, the multi-stage connecting rods are still prone to slight vibrating after unfolded.

Add support mechanism to limit the horizontal displacement of the multi-rod after unfolded.

10.3 Versatile Applications

10.3.1 Multi-Rod Structure

On the one hand, the linkage connection and dimensions can be modified to meet the extension requirements in different situations. On the other hand, end-effectors can be added to the linkage mechanism to accomplish more demanding tasks.

10.3.2 Bilateral Process and Compatibility

On the one hand, the size and connection of the linkage can be adjusted so that the camera is direct-above the plant after unfolding, so that the robot can achieve simultaneous recognition of plants with different planting spacing. On the other hand, the algorithm of machine vision can be adjusted to recognize strawberry plants obliquely downward by adjusting on the existing mechanical structure.

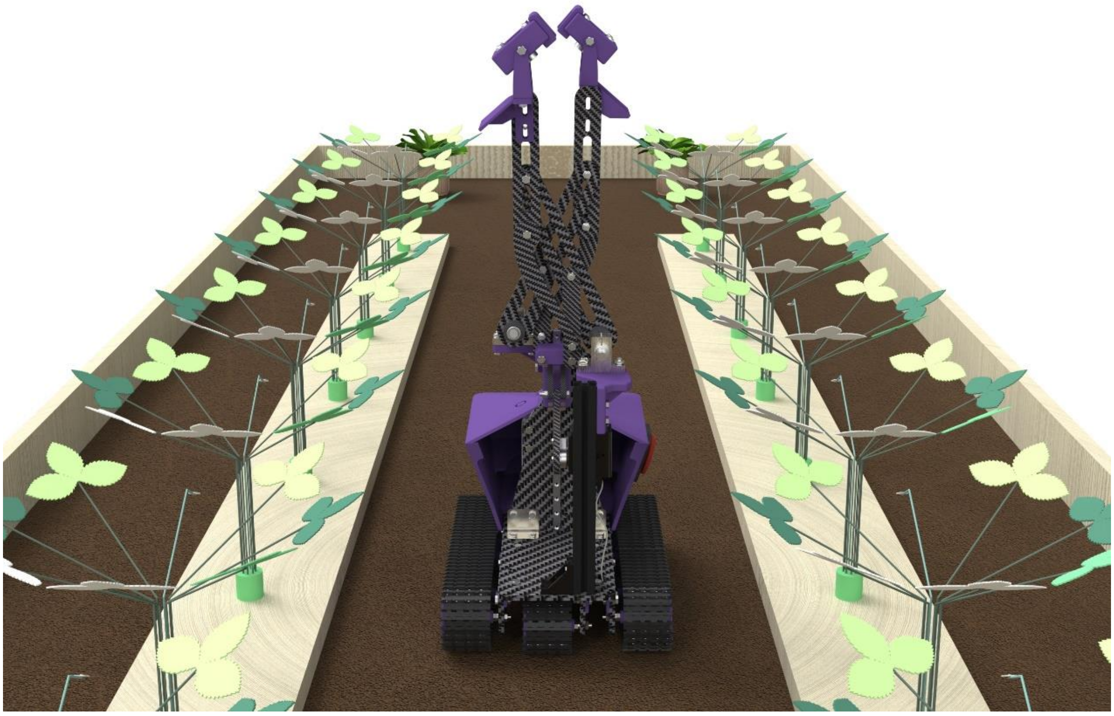


Figure 10-3 Schematic diagram of the robot for bilateral identification