Fundamentals of Product Design and Development

ME 4500

NUSRI

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Group A3

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Content

Abstract

The environment of the fire scene is often very complex and uncertain, which will bring great risk to the safety of firefighters. How to explore the fire scene and provide good information for firefighters to rescue is our research topic.

First of all, we clarified our design objectives. We studied some products on the market, analyzed the customer's needs, generated and selected concepts, and then carried out prototype design, manufacturing and testing of the products.

Through the above process, we managed to make a prototype for our project, an Intelligent Fire Reconciliation Robot. Based on Arduino, the robot uses four Mecanum wheels for forward and lateral movement, which have good mobility and can adapt to the complex environment of the fire scene. Regarding intelligence collection, we have installed an ESP32 camera, which can clearly provide fire site information for firefighters on screen. In a smoke environment, the flame detector and ultrasonic sensor will work. The flame detector can analyze the distance and scale of the flame using infrared, and the ultrasonic sensor can detect nearby obstacles. The information from the sensors will be transmitted to the user's app through Bluetooth, allowing firefighters to make a brief analysis of the fire scene.

We believe that our project is very significant. Firefighters can use our robot to quickly explore a smoke-free and smokey environment, help them evaluate the situation and make the best rescue plan to reduce the risk

1. Introduction

1.1 Background

The Fire and Rescue Bureau of the Ministry of Emergency Management announced to the media the 2021 national fire and rescue team’s response to fire situations. According to statistics, last year, fire and rescue teams across the country responded to 1.956 million reports of various types of police situations, dispatched 20.408 million fire and rescue personnel and 3.636 million fire trucks, rescued 195,000 people from the scene of disasters and evacuated 467,000 people in distress. A total of 748,000 fires were reported, with 1,987 deaths and 2,225 injuries, and direct property losses of 6.75 billion yuan. [1]

The situation of fire accidents is complicated, and inspection, detection and fire fighting and rescue are extremely difficult. The reasons are as follows: manual routine inspection is subjective and easy to miss inspection; The fire site is prone to toxic corrosion and high risk; During emergency valve closing and plugging, the disposal objects are diverse and the disposal operations are complex; The explosion site is prone to multiple explosions, and the firefighters suffer heavy casualties, so the conventional fire extinguishing means are facing severe challenges, and it is imperative to replace with robot.

Fire-fighting robot is a kind of special robot, which plays an increasingly decisive role in fire-fighting and rescue. Especially, with the increasing number of large petrochemical enterprises, tunnels and subways, disaster hazards such as oil, gas, toxic gas leakage and explosion, tunnel and subway collapse continue to increase. The fire robot can replace the fire rescue personnel to enter the scene of inflammable and explosive, toxic, hypoxia, smoke and other dangerous disasters, for detection, feedback, disposal operations, improving efficiency, reducing the risk of casualties.

Since 2014, the market scale of China's firefighting robot has continued to grow, increasing to 1.10 billion yuan in 2018, with a year-on-year growth of 54.93%. It is preliminarily estimated that by 2020, the market scale of China's fire robot industry will reach 1.82 billion yuan, and by 2023 will grow to 3.69 billion yuan. [2]

1.2 Problem Statement

The objective of this project is to design and manufacture an intelligent fire reconnaissance robot that can be smoothly controlled remotely by firemen to automatically detect the source of fire in both smoke and smoke-free environments in order to reduce casualties.

1.3 Objective

The vehicle can be remotely controlled smoothly within response time of 0.5s.

The vehicle has high temperature tolerance and fire-proof.

The vehicle is small in size and can move in confined space and rotate in-place to adapt to narrow-space disposal.

The vehicle is equipped with a camera in-front to detect the fire source in smoke-free environments and image is sent to the controller through WIFI.

The vehicle is equipped with an ultrasonic sensor to sent distance from obstacles to the controller through blue-tooth to assist decision-making for movement in smoky environments.

The vehicle is equipped with a multi-directional fire senor to detect the direction and distance of the fire and sent the information to the controller in smoky environments.

2. Literature review : product search

Since our product was originally aimed for helping firefighters to get information from the fire scenes it has to be smart enough to go through complex environments in different fire scenes. Therefore, we define it as an intelligent fire-fighting robot that can be smoothly controlled remotely and automatically detect the source of fire in smoke and smoke-free environments.

So basically, we have to make the robot agile and at the same time, stable.

To begin with, as figure 2-1, we have done some relative search on the internet and we have found that rescue robots or fire-distinguishing robots in fire scenes have already become a heated product both in domestic and foreign markets. Study shows that the average annual sales growth rate of China's fire protection product market in recent five years has reached 17%. At this stage, China has developed a variety of fire fighting robots with sound functions and rich types. Some robots can play multiple fire fighting auxiliary functions, and the market scale has also continued to grow. As of 2020, the market scale of fire fighting robots in China is 1.57 billion yuan. From 2015 to 2020, the composite growth rate of the market model is 38.33%. In 2021, the market scale has reached 1.81 billion yuan.

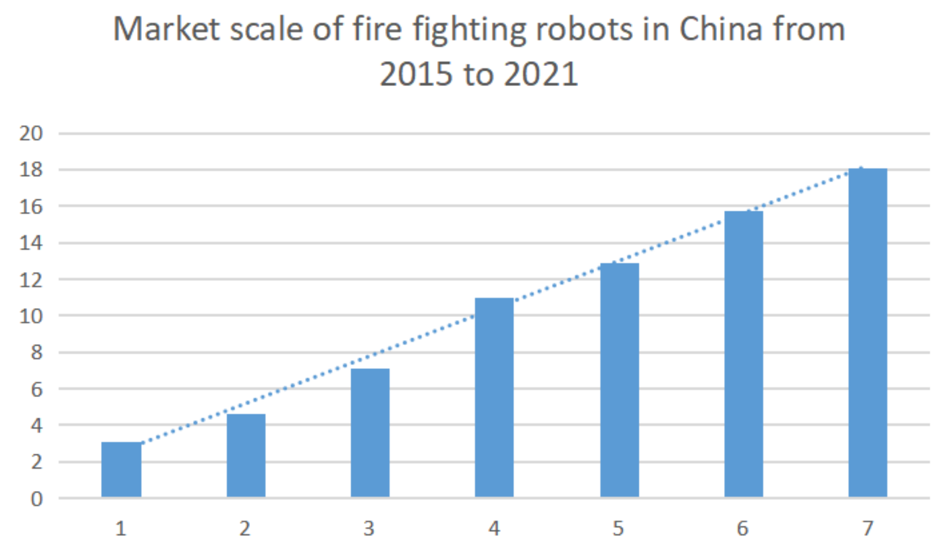


Figure 2-1

Therefore, it is worth a lot that we do some patent search and inquire information about similar products with similar functions on the market, and got a rough understanding of the implementation principles of these functions in their products.

We did some study on this Explosion-proof fire scout robot called “QiTeng Robot” which was somewhat different from the final design we adopted as figure 2-2.

First it is much larger in size and it has a pump that allows it to participate in the fire fighting apart from just exploring the way and gathering information from fire scenes, which we have discussed and dismissed as unhelpful on our product due to the relatively small size of our robot. Some improvements were considered otherwise.

Second it has caterpillar tracks as its dynamic system that allows it to easily cross terrain obstacles. which we have also discussed and regarded as not convenient when it comes to steering and lateral translation.

Figure 2-2

However, there were indeed some rather constructive functional designs that had something in common with our ideas.

To begin with, the robot adopts wireless remotely control design as figure 2-3, which is the premise to realize the main functions of the robot. Wired connection will not only restrict the robot's movement, but also require high quality wire rods.

Figure 2-3

Further more, this robot has an advanced gas sensor. It has been reflected in many studies that the heavy smoke mixed with various toxic and harmful gases is one of the fatal parts in a fire scene, not only because they are easy to suffocate people, but also because the flammable and explosive gases such as carbon oxides mixed in them are easy to cause secondary explosion.

So it is equipped with the gas sensor as figure 2-4 that can not only detect the gas type but also the gas concentration.

Figure 2-4

In addition, it is equipped with a lifting platform as figure 2-5 that allows the camera to detect higher and farther field environments instead of being blocked by obstruction. Since we intended to design a robot with camera, a platform is highly needed for a larger reconnaissance range.

Figure 2-5

In the end, it is equipped with a photo transmission control box as figure 2-6 that's capable of both photo and image transmission. This should also be an essential part if we mainly consider the camera as the guidance and auxiliary control equipment. We would need a module that can transmit images in real time.

Figure 2-6

These are practical functions that are adjusted to complex environments and considerate for firefighters. However we should also consider the requirements of our potential customers as they may apply our devices in a real fight that’s concerned with their own safety.

Therefore we have to make a list of our customer needs to check out.

3. Customer requirements

According to the most popular requirements for fire rescue robots we have gathered the most important ones and classified them according to their priorities and put the list below as table 3-1.

NO.	Customer Needs	Imporatnce
1	Easy to operate	4
2	Easy to maintain	3
3	Remote control	5
4	Real-time feedback	5
5	Smoothly moving	5
6	Locate combustion source	5
7	Detect combustible and poisonous gas	5
8	Low cost	3
9	Adapt to smoking and non-smoking environments	5
10	Friendly-looking	2

Table 3-1

4. Concept generation

Based on customer requirements and the popular functions from the market we came up with four original concepts as our candidates.

The first is a camera-capable tracked robot of strong trafficability with a fan as figure 4-1.

As for movement, we use tracks to adapt to complex environments at fire sites, and a fan is equipped to help extinguish the fire. In terms of detection, a camera is used for remote observation and control.

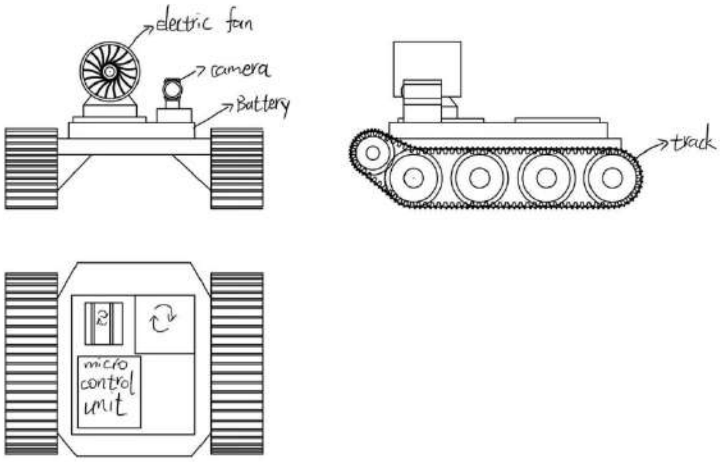


Figure 4-1

The second, a quadrupedal robot with higher adaptability to environment as figure 4-2.

The tracks are replaced by a quadrupedal design to improve its adaptability since the actual environment will be more of obstacles that tracks can not go across in a fire site. In terms of detection, a flame sensor and an ultrasonic sensor will be used for detection, which may improve the identification accuracy rate.

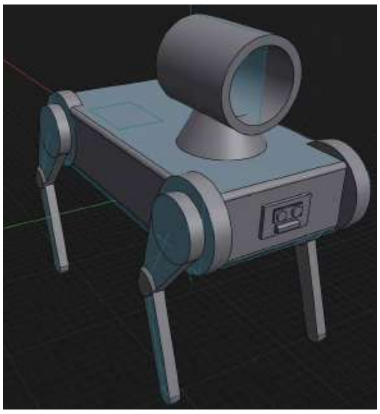


Figure 4-2

The third one, A four-wheel driving mobile robot with flame detection, ultrasonic obstacle avoidance and automatic fire extinguishing as figure 4-3.

Instead of a fan, we use a water pump to help put out the fire. And considering the cost and the size, we install four wheels rather than complex robot legs to move it.

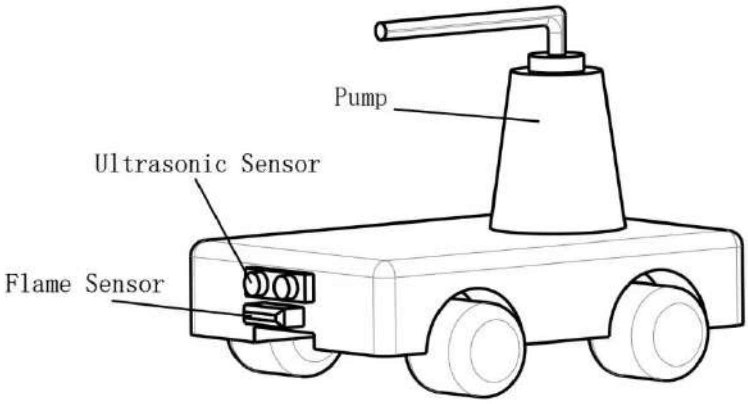


Figure 4-3

The last one, a A four-wheel driving mobile robot with flame detection, ultrasonic obstacle avoidance and automatic fire extinguishing and a camera as figure 4-4.

Different from the previous scheme, this scheme mainly relies on the camera to detect. It also has a water pump over here, but we replaced the wheels with Mecanum wheels, a wheel that allows lateral slip, which will enable it to move more smoothly.

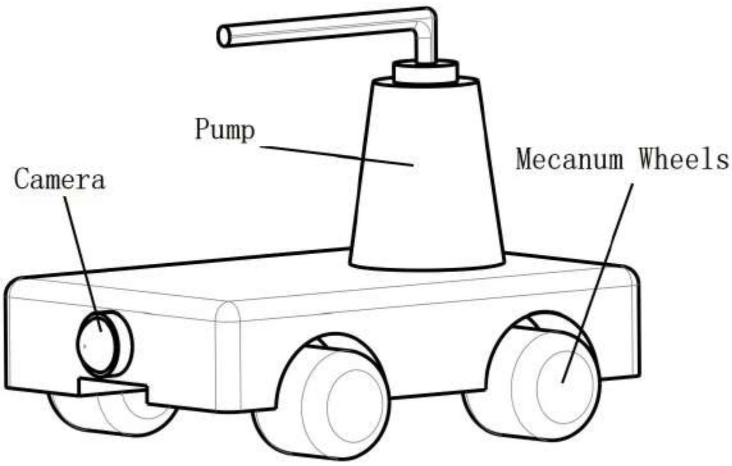


Figure 4-4

4.1 Concept selection

After the concept generation we set up scoring criteria to score the four concepts according to them as table 4-1. Basically the one that has the highest score would be our final option.

Relative Performance	Rating
Much worse than our expectation	1
Worse than our expectation	2
Same as our expectation	3
Better than our expectation	4
Much better than our expectation	5

Table 4-1

Therefore we did the scoring and ranking job and listed the result as a form in table 4-2.

		concepts							
		A		B		C		D	
selection criteria	weight	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score	Rating	Weighted score
Easy to operate	9%	4	0.36	2	0.18	4	0.36	4	0.36
Easy to maintain	7%	3	0.21	2	0.14	4	0.28	3	0.21
Remote control	11%	3	0.33	3	0.33	3	0.33	3	0.33
Real-time feedback	11%	3	0.33	3	0.33	4	0.44	4	0.44
Smoothly moving	11%	2	0.22	4	0.44	3	0.33	4	0.44
Locate combustion source	11%	3	0.33	3	0.33	3	0.33	4	0.44
Detect combustible and poisonous gas	11%	3	0.33	2	0.22	3	0.33	3	0.33
Help put out fire	7%	3	0.21	2	0.14	2	0.14	3	0.21
Low cost	7%	3	0.21	1	0.07	4	0.28	4	0.28
Adapt to smoking and non-smoking environments	11%	3	0.33	3	0.33	3	0.33	4	0.44
Friendly-looking	4%	1	0.04	4	0.16	3	0.12	3	0.12
Total score		3	2.9	4	2.67	2	3.27	1	3.6
Continue?		No		No		No		Develop	

Table 4-2

After the ranking we boiled down to concept 4 as the final candidate due to its outstanding performance. Concept 4 will solve our problems to the greatest extent for three main reasons below

first of all, macenum wheels make it easier to move in any direction, which makes great contribution to the improvement of convenience in operation.

In addition, concept 4 has less jiggling that makes the sensors difficult to detect obstacles, making it more precise in locating.

4.2 Conclusion and development

However, the original concept 4 has only a camera in the front so when it comes to fire scenes with thick smoke it may become blind at some time, so it is more likely to bump into barriers.

Therefore we decided to add the ultrasonic sensor and the flame sensor to the vehicle in concept 4 so that it can be more steady when running in an actual fire scene.

In conclusion we chose macenum wheels as the dynamic system for it is agile when it execute instructions like steering and leteral translation. As for the detecting system we applied ultrasonic sensor; flame sensor and real-time camera to guarantee the stability of our function. When it comes to smoky environment the robot would switch to automatic mode that can avoid obstacles as the ultrasonic sensor send back the pulse and the MCU converted analog quantity into digital quantity to decide the distance. The flame sensor detects the Detect the wavelength of infrared light and return it to the MCU. The distance from the flame and the size of the flame are represented by the voltage.

4.3 Selection of materials

Macnum wheels vehicle prototype

Figure 4-5 Macnum wheels prototype

This prototype with good structure can be used to complete all the required functions and its volume is only 25×15×15 cm^3.

Ultrasonic module HC-SR04

Figure 4-6 HC-SR04

As figure 4-6, this module has stable performance, accurate measuring distance, high precision and small blind area with detection range from 2cm to 450cm.

Five-way flame sensor

Figure 4-7 Five-way flame sensor

As figure 4-7, this module is a five-in-one flame sensor with larger detection range of 120°and it can give both analog output and digital output.

Esp-32 cam

Figure 4-8 Esp-32 cam

As figure 4-8, it is a cost-effective camera module which supports secondary development.

Bluetooth module ZS-040

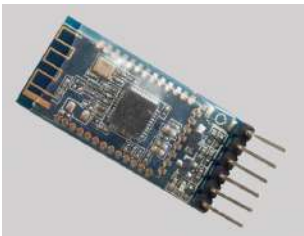


Figure 4-9 ZS-040

As figure 4-9, this Bluetooth module has the advantages of low cost, small size, low power consumption and high sensitivity for sending and receiving information, working range ≤ 30m.

All metal TT motor

Figure 4-10 All metal TT motor

Compared to normal TT motors, this one has higher stability and provides more power.

Arduino Uno board

Arduino Nano board

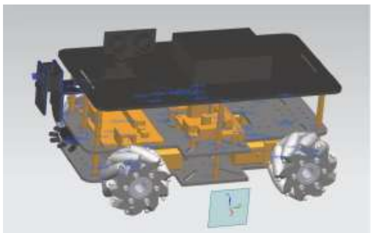
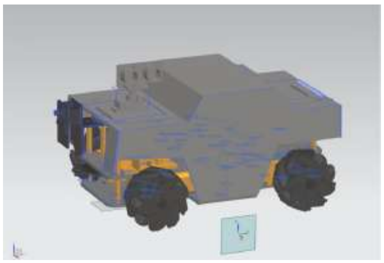
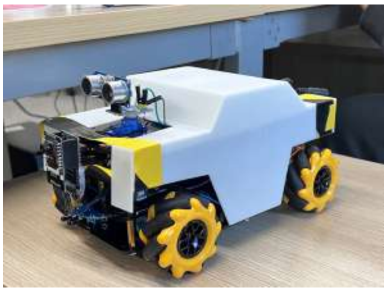
12V battery

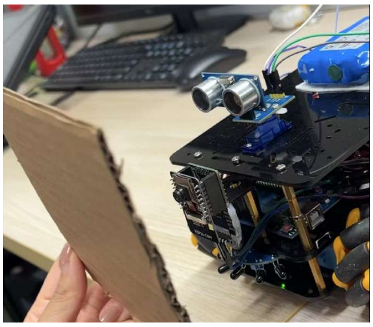
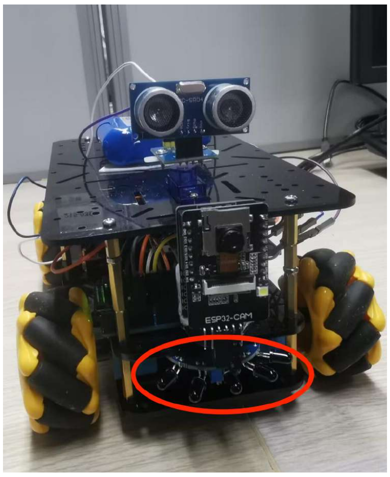
4.4 Item purchase and cost

No.	Description(s) of item(s)	Qty Req'd	Unit Price (¥)	Sub-Total (¥)
1	Macnum wheels vehicle prototype	1	98	98
2	Flame sensor	1	26.67	26.67
3	12V battery	1	48	48
5	Arduino Uno board	1	65.7	65.7
6	Arduino Nano board	1	28	28
7	TT motor	4	11.3	45.2
8	Esp-32 cam	1	53.7	53.7
9	Ultrasonic module	1	25	25
15	Bluetooth module	2	16.8	33.6
TOTAL		13		423.87

Table 4-3 item table

5. Fabrication process

Step	Operation	Result
1	Build 3D assembly model	
2	Build enclosure model and 3D print	
3	Make an inventory of materials and assemble the vehicle	
4	Install ESP32 camera	
5	Test ESP32 camera	

6	Install ultrasonic sensor	
7	Test ultrasonic sensor	 
8	Install fire sensor	
9	Test fire sensor	

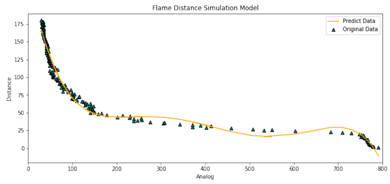
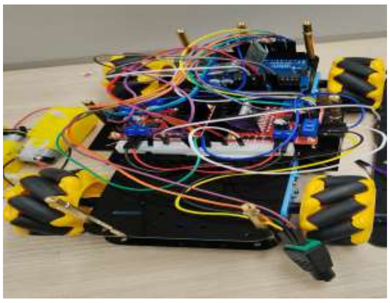
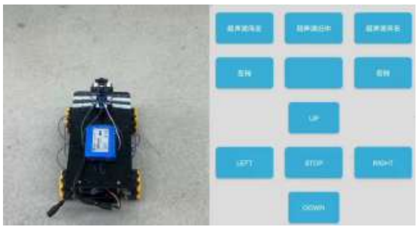
10	Fire sensor distance Curve fitting	
11	Install Mecanum wheel	
12	Test Mecanum wheel	
13	Final structural testing and real practice	

Table 5-1

6. Testing of prototype

6.1 Overall function

Figure 6-1 shows the function flow of the prototype in both smoke-free environment and smoky environment. In the smoke-free environment, the camera at the front of the vehicle will work to provides the information of the obstacles and the location of the fire source. The operator can access the content of this camera and then remotely control the vehicle to search the fire. In the smoky environment, the camera would not be helpful since smoke cover everything. An ultrasonic module is added to the vehicle to detect the obstacles and then send the information to the operator, a flame sensor is used to detect to fire source and also send the results to the operator. The operator can remotely control the vehicle to search the fire according to the feedback of these two sensors.

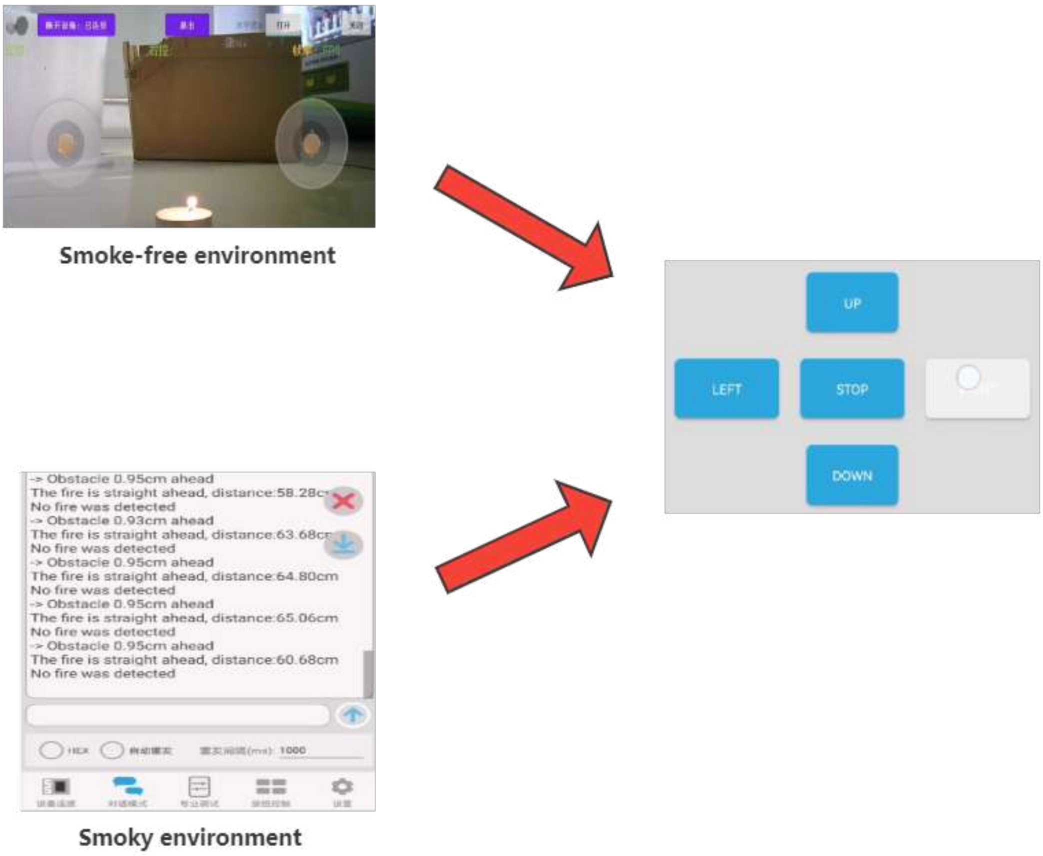


Figure 6-1 Overall function flow

6.2 Movement testing

The Macnum wheels provide the ability to move in four directions--font, back, left and right.

Moving forward as figure 6-2

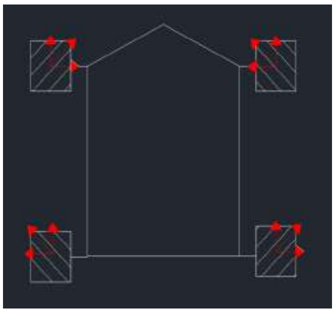


Figure 6-2 Friction force of moving forward

Figure 6-2 shows the friction force applying on each Macnum wheels when four wheels moving forward. The resultant force is forward after the left and right forces cancel each other which makes the vehicle move forward.

Moving backward

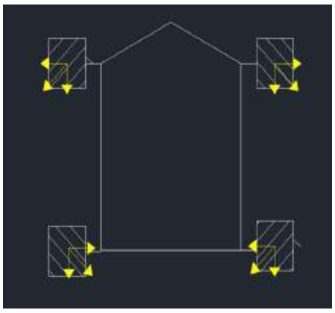


Figure 6-3 Friction force of moving backward

Figure 6-3 shows the friction force applying on each Macnum wheels when four wheels moving backward. The resultant force is backward after the left and right forces cancel each other which makes the vehicle move backward.

Shifting to the left

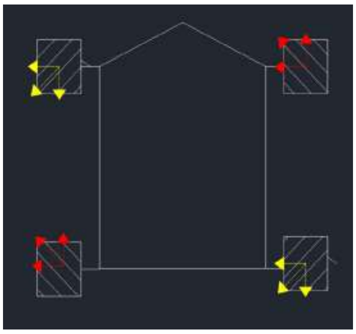


Figure 6-4 Friction force of shifting to the left

Figure 6-4 above shows the friction force applying on each Macnum wheels when the left front wheel and the right rear wheel move backward and the other two wheels move forward, the resultant force will point to left because the forward and backward forces cancel each other out which makes the vehicle shift to the left.

Shifting to the right

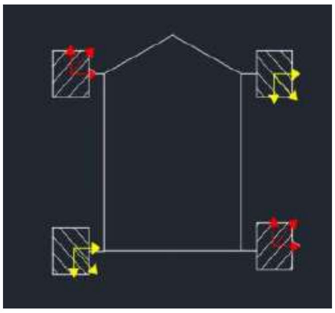


Figure 6-5 Friction force of shifting to the right

Figure 6-5 above shows the friction force applying on each Macnum wheels when the left front wheel and the right rear wheel move forward and the other two wheels move backward, the resultant force will point to right because the forward and backward forces cancel each other out which makes the vehicle shift to the right.

Rotate

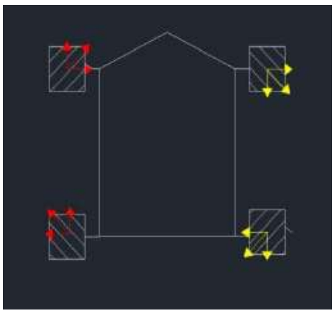


Figure 6-6 Friction force of rotation

When the left side wheels and the right side wheels rotate in different directions, the differential speed will help the vehicle spin in place.

6.3 Ultrasonic module testing

This module has three components: an Arduino Nano, an HC-SR04 sensor and a servo, and the whole module is installed on the top of the vehicle. The HC-SR04 sensor is an ultrasonic sensor for obstacle detection. It is a popular sensor that uses ultrasound to accurately measure obstacles within 4 meters and output the echo time, which can be used to detect the obstacle and the distance from it. The servo is used to change the direction of the sensor, which can widen the sensor's field of vision. The Nano controls the servo and sensor and communicates with the phone through Bluetooth.

This module is designed to detect obstacles around the vehicle and send the distance data to users, which can help them monitor the vehicle in a low-visibility environment.

In the testing stage, as figure 6-7 shows, we used simulation software to test the feasibility of code and wiring, which was easier for us to debug. Then we put it into practice and connected the module to the phone application through Bluetooth. Since the sensor was not precise enough, we tried to calibrate the distance algorithm to improve accuracy. As figure 6-8 shows, during many times testing, we corrected the parameters and managed to make the distance detection very precise. After installing the module and testing, our prototype has proven that it can efficiently explore a fire site and move smoothly in smoke environments.

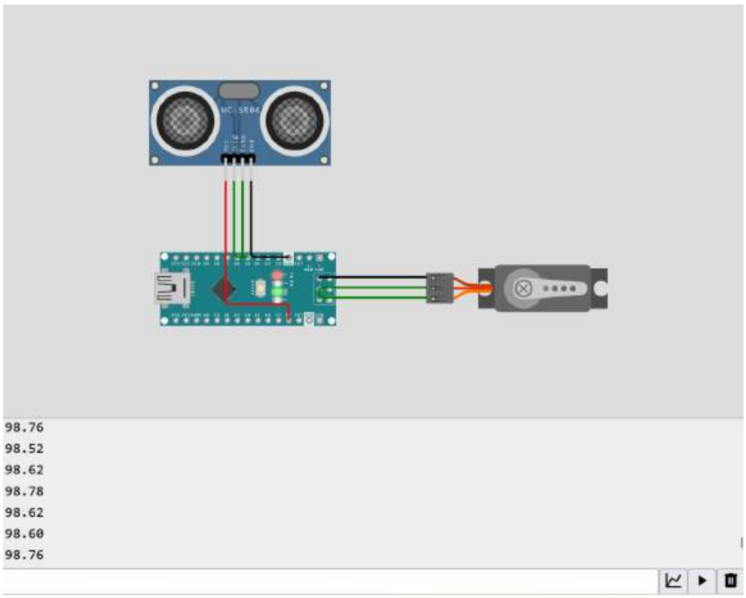


Figure 6-7

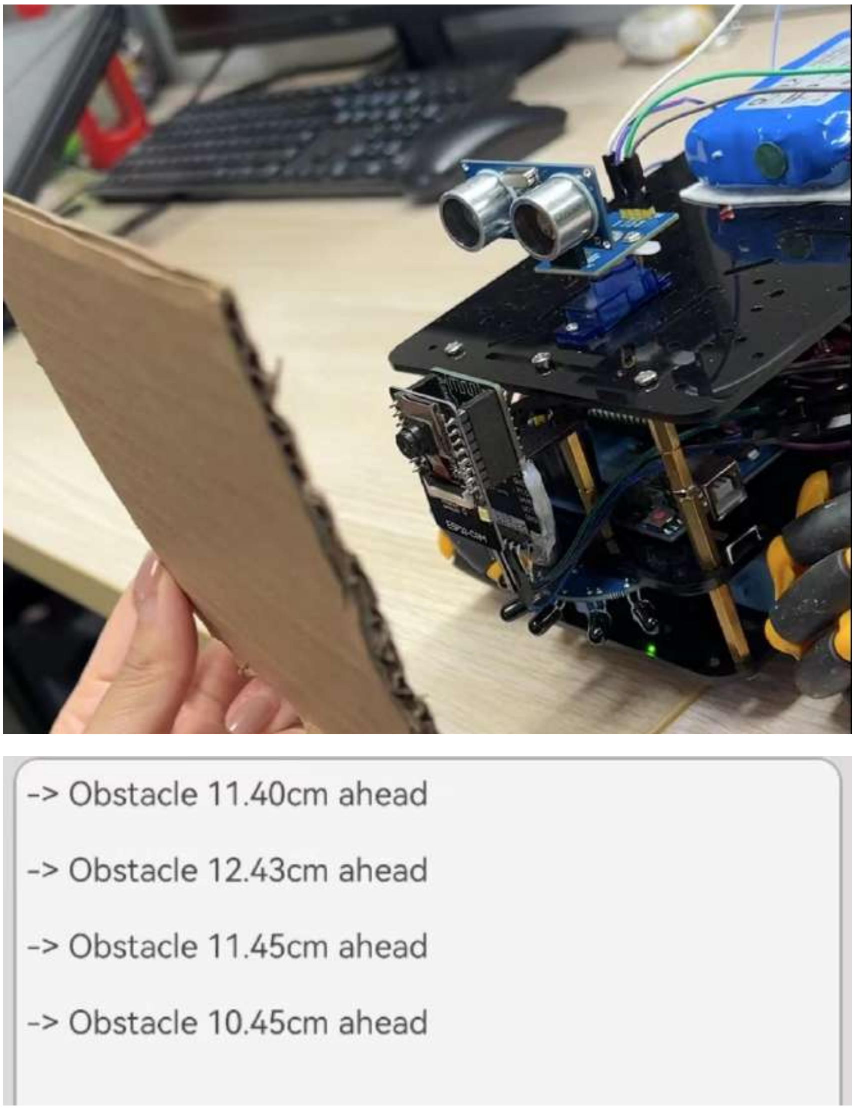


Figure 6-8

6.4 Flame Sensor Module Testing

Our product uses a five-way flame sensor and connects it to a Bluetooth module and a microcontroller. The flame sensor is positioned in the middle of the front of the robot.

On the flame sensing module, our product enables multi-directional fire detection and can display the relevant direction detected and the distance between the robot and the fire source in real-time Bluetooth transmission to the mobile app.

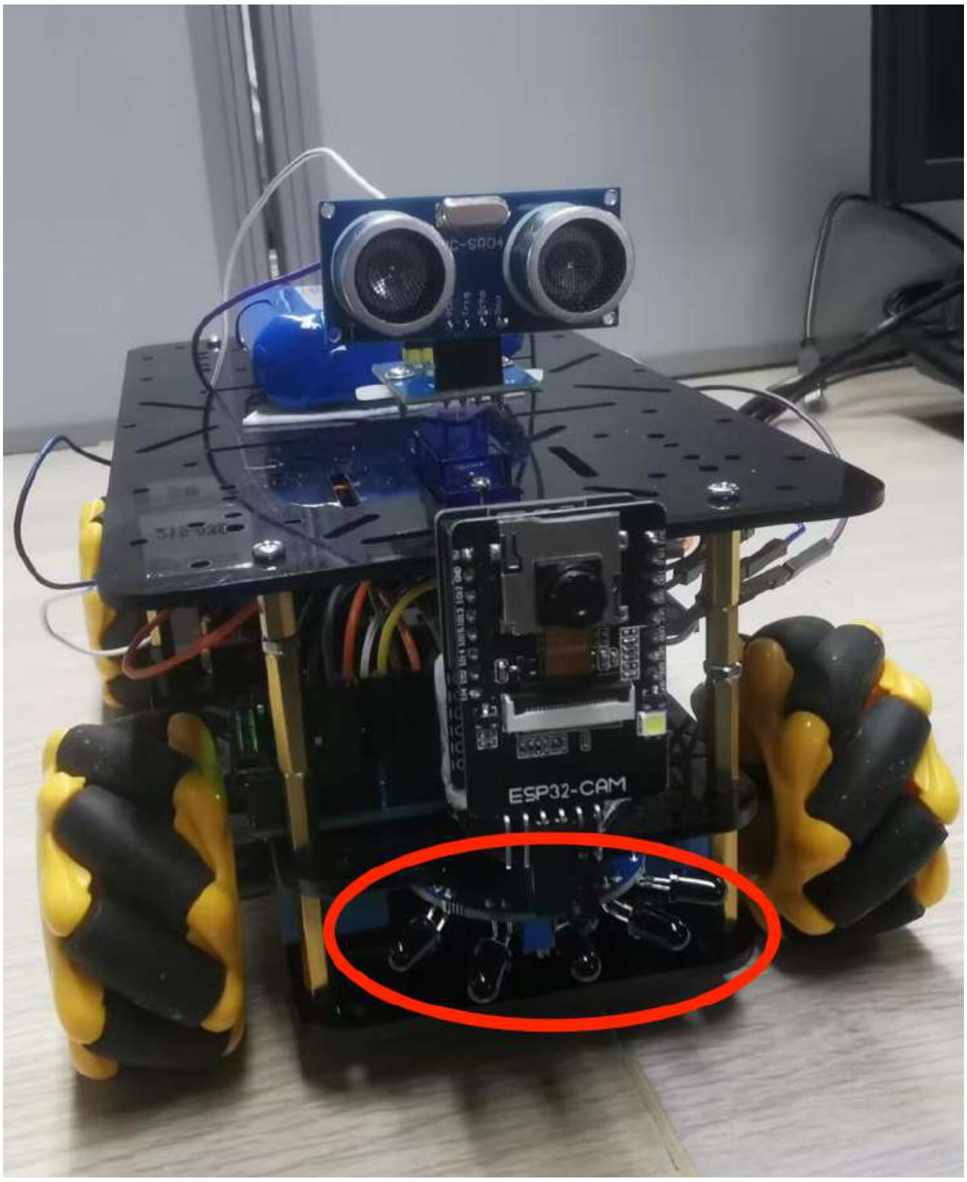


Figure 6-9 Position of Flame Sensor

6.4.1 Introduction to the Flame Sensor

The flame sensor is a sensor used by the robot to search for the source of fire. The flame sensor uses infrared light, which is very sensitive to flame, to detect the flame using a special infrared receiver tube, and then converts the brightness of the flame into a level signal that varies from high to low, which is fed into the central processor, which makes the corresponding program according to the change in signal.

First， our products use a five-way flame sensor, and we use the three lead angles marked in the figure 6-10 below.Our team connected the flame sensor to the microcontroller via serial wiring, wrote a complete program and burned it into the sensor, and tested it several times. Now, with the flame sensor, our product not only detects the presence of a fire source but also enables the detection of a fire source in three directions: which are front, left, and right.

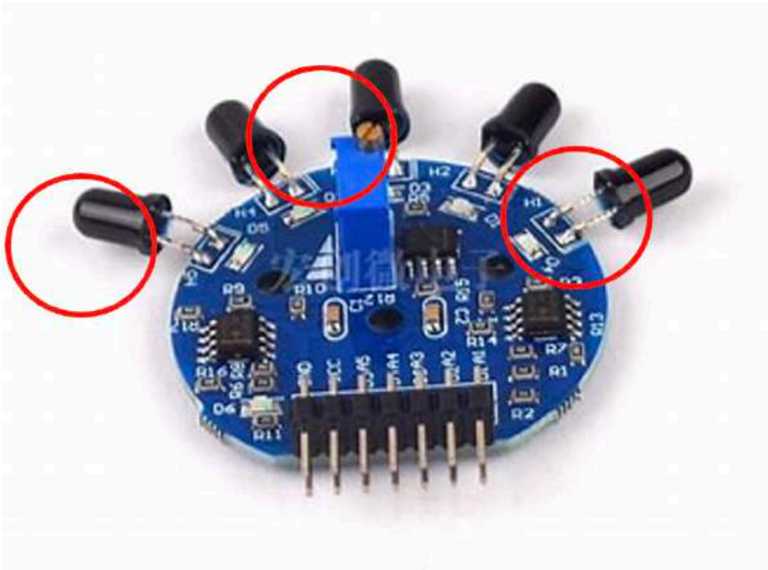


Figure 6-10 Five-way Flame Sensor

6.4.2 Flame sensor and Bluetooth communication

The Bluetooth module is a PCBA board with integrated Bluetooth functionality for data transmission. The Bluetooth module can be connected to the mobile phone via Bluetooth and can be used for data communication. Using the SoftwareSerial library, ordinary digital pins can be simulated as serial pins on the Arduino board by calling software library.

Using the constructor of the SoftwareSerial class, the soft serial RX and TX pins are specified for Bluetooth communication of the flame sensor results

6.4.3 Flame Distance Detection

During the debugging of the flame sensor, we found that if we connect the flame sensor to the digital interface of the microcontroller, it only returns high and low levels indicating whether there is a fire or not. But if we connect the flame sensor to the analogue signal of the microcontroller, we get a wide range of analogue quantities.

It is observed that the flame sensor returns an analogue quantity related to the distance of the flame. Figure 6-11 shows the relevant analogue quantity returned by the sensor and Figure 6-12 shows the corresponding distance between the robot and the flame at that time.

Figure 6-11 Analogue Quantity Returned by Flame Sensor

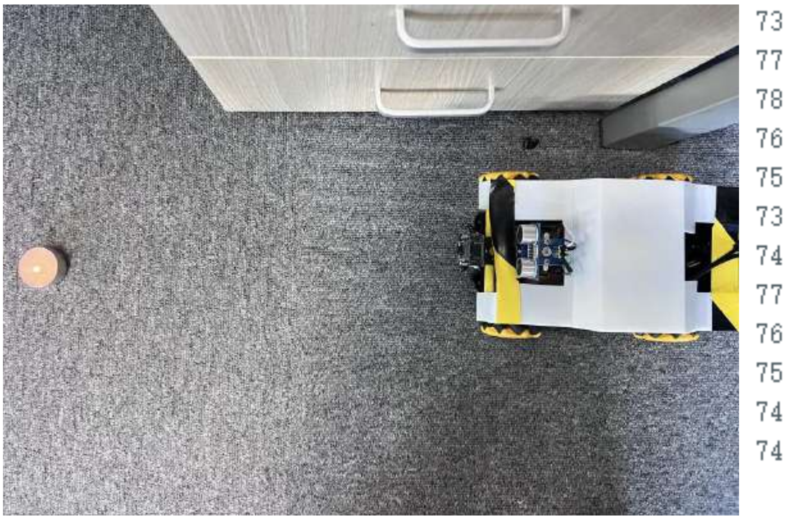


Figure 6-12 Distance Between the Robot and the Flame

To better visualise the data, a dataset of analogue quantities returned by the flame sensor about the flame distance was collected experimentally and hopefully, correlations were established using machine learning methods.

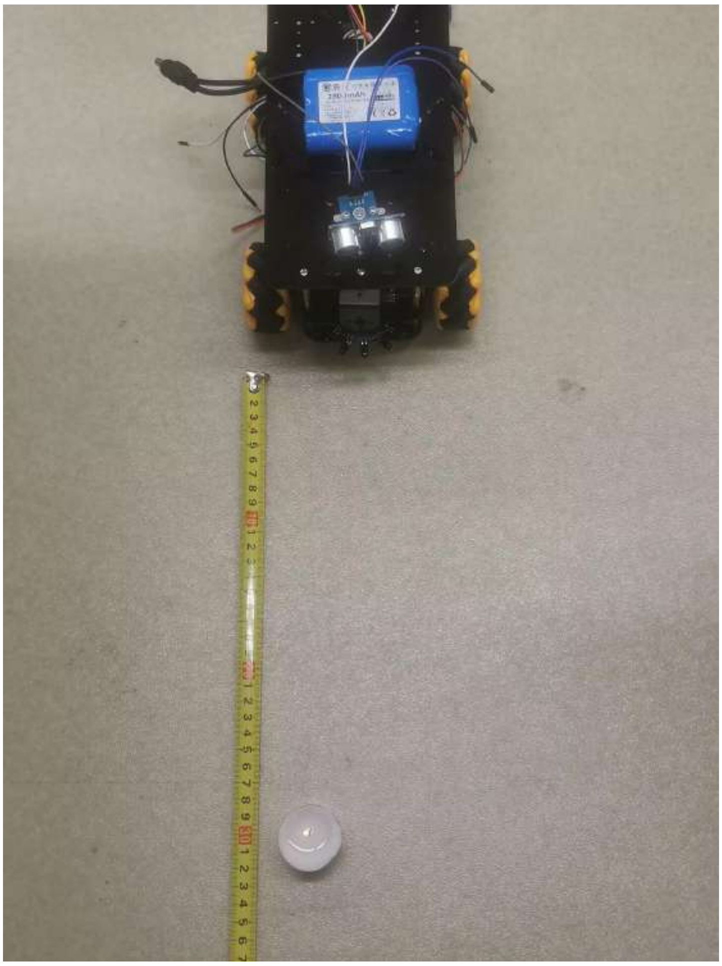


Figure 6-14 Flame and Distance Data Set Acquisition Experiment

Table 6-1 shows a portion of the dataset we collected from our experiments. We used polynomial regression to build a model that reflects the correlation between the simulated quantities and distances, and the model works as shown in Figure 6-15. Since the Arduino cannot directly import models built in Python and the regression algorithm can simulate the results very well. We ended up using a polynomial regression algorithm that can be directly exported. This is the polynomial we fitted

$$distance\ y = (-0.000000000030357938)x^5 + (0.000000065089357551)x^4 + (-0.000051795159894221)x^3 +$$

$$(0.0189001761165646)x^2 + (-3.1981401354342127)x + 247.3049576981166$$

, which we applied to the relevant algorithm and burned into the microcontroller. Based on this, we established a correlation between the simulated quantities and the distance to the fire source.

x	y
791	1
780	2
777	3
774	4
772	5
770	6
769	7
768	8
768	9
766	10
765	11
767	12

Table 6-1

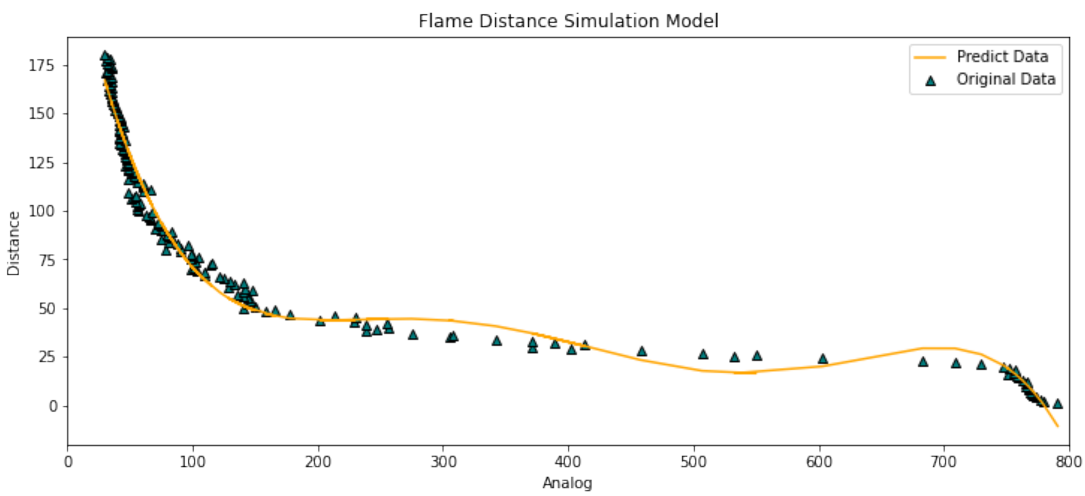


Figure 6-15 Flame Distance Simulation Model

6.4.4 App Display

Figure 6-16 shows the app interface of our product, which displays the sensor information we transmit via Bluetooth in real-time. The data that can be displayed includes whether a flame is detected, the direction of the flame, and the distance between the flame and the robot.

The content of the ultrasonic sensors we use is also monitored in real-time by the app, including whether there are any obstacles ahead and the distance between them.

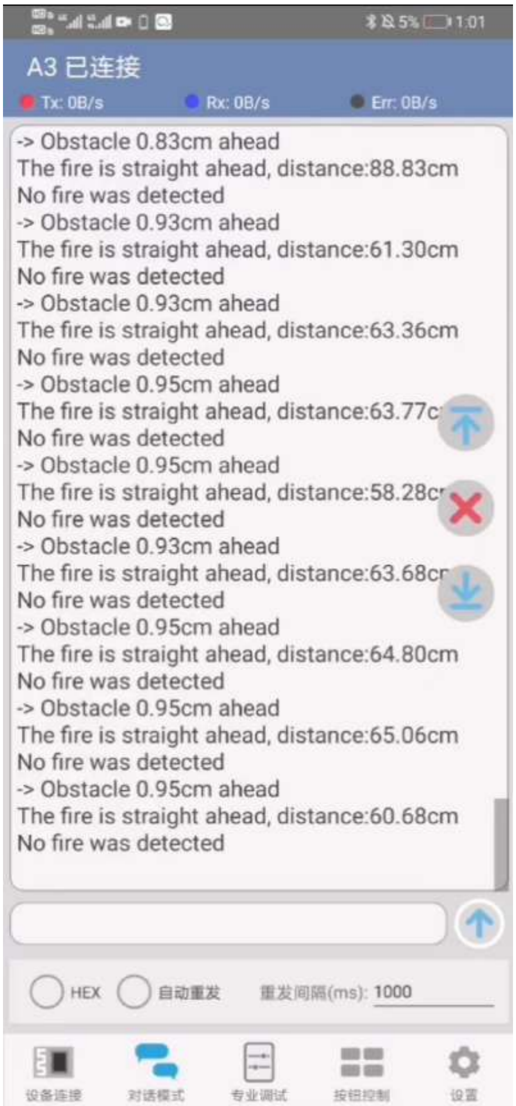


Figure 6-16 App Display

6.5 Testing of the prototype——ESP32 CAM

ESP32-CAM is the latest small-size camera module released by Essence, which drives camera ov2640, 20MHz clock frequency. The module can work independently as the smallest system, with a size of only 2740.54.5mm, and a deep sleep current as low as 6mA. ESP32-CAM can be widely used in various robotics applications, suitable for home smart devices, industrial wireless control, wireless monitoring, QR wireless identification, wireless positioning system signals, and other applications. It is an ideal solution for rescue robot applications. ESP32-CAM adopts a DIP package and can be used directly by plugging in the bottom plate, realizing rapid production of products, providing customers with highly reliable connection methods, and being convenient for application on various occasions. It is an independent monitor of the robot. As the Figure 6-17 shows.

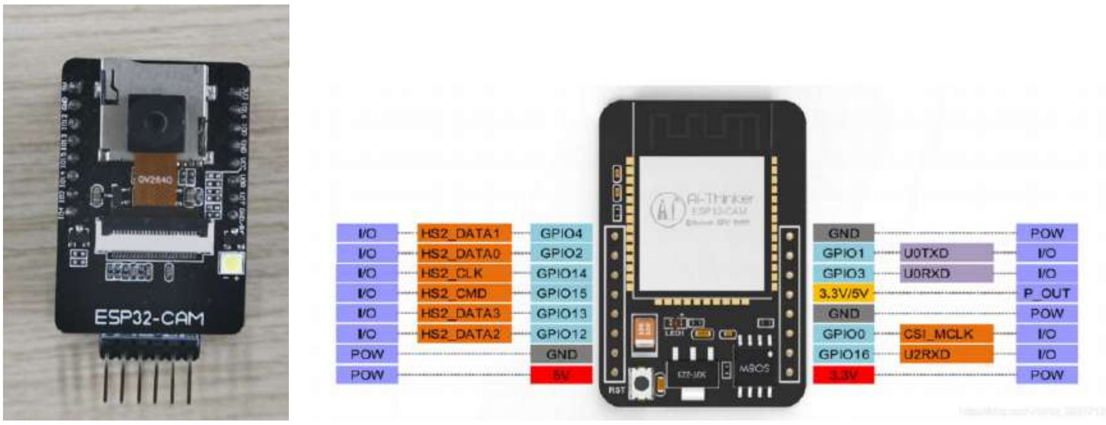


Figure 6-17 ESP32-CAM

Because this camera module is fully functional, it is also easy to use. After configuring the relevant download environment on the software used, the Arduino IDE, open the camera program inside the examples and change the program to

Block outline 11: //#define CAMERA_MODEL_WROVER_KIT // Has PSRAM // Mask this line because it does not use the Axiomtek camera;

unmask line 17: #/define CAMERA_MODEL_AI_THINKER // Has PSRAM //;

Remove the mask from this line and use the Axiomtek camera;

Lines 22 and 23 should be changed to your own 2.4G WiFi name and password respectively.

Compile and download the program, after the program is uploaded, open the serial monitor, set the baud rate to 115200, press the reset button and the serial port will output data, you need to wait a while for the module to be connected to WiFi and configured; after the configuration is complete the serial port will output an IP address, open the IP address in the mobile browser to enter the web configuration link, thus displaying the screen.

In addition to this, our team connected the camera display screen to the mobile phone via software. After the camera module is connected to the MCU for power supply, the camera can be connected through the mobile phone software to observe the sense of the mobile phone. As the Figure 6-18 shows.

Figure 6-18 Camera test screen

7. Challenges and solutions

During the design and production of our products, we have inevitably encountered some challenges and we have come up with our solutions.

First of all, there are some of the challenges we encountered.

Firstly, as the disaster we chose was a fire, the scene of the rescue was usually accompanied by high temperatures which would most likely melt the casing of our equipment or the motherboard, thus rendering our products inoperable.

Secondly, after the product has been assembled in practice, we have found that the translational movement of the product is greatly influenced by the distribution of the mass of the vehicle due to changes in motor performance and wheel speed and that the speed and flexibility of the translational movement of the trolley will be affected by changes in mass.

Thirdly, we have to detect the distance of the fire source and our fire detection sensors are affected by a variety of factors, such as the combustion of different materials, the intensity of the fire, and the intensity of the ambient light, all of which can vary and affect the accuracy of the data results.

Each of the three challenges arising from the above has also been addressed by our team members with targeted solutions.

Firstly, to address the issue of high temperatures, we designed a heat-resistant housing for the robot and coated it with fire-resistant paint. Also, our Mecenum wheel was designed to use fire-resistant tires with good fire retardant properties.

Secondly, we did a lot of experiments to vary the speed of the wheel to suit the unbalanced weight, from which we found patterns that solved the problem of unstable translational movement of the product.

Thirdly, concerning the flame sensor, to simulate the fire scene as realistically as possible and to obtain better measurement results, we tested the distance of the fire under fixed light conditions and fire sources to minimize the variation of the influencing factors, so that the flame sensor could function effectively and collect relevant data.

8. Future Improvements

Thermal imaging camera. The fire scene is filled with smoke, which contains a large amount of micron-level carbon black particles, which are very easy to absorb visible light, resulting in a significant reduction in the visible distance, impacting on the search and rescue of trapped people. Ordinary fire sensors are easily affected by combustion materials, combustion intensity and other aspects, resulting in inaccurate detection distance and weak stability. Thermal imaging thermometers can search for heat sources in a variety of environments, discover the actual ignition point, and transmit color-coded images in real time to a computer, mobile phone or large-screen display, assist fire fighters to accurately judge the spread trend of fire, and send the real-time situation back to the command center for risk assessment and rescue command and dispatch.

Figure 8-1 Thermal Imaging Camera

Lidar. Ultrasonic sensor for obstacle avoidance has limited accuracy, and improvements could be made through ladar SLAM technology, which also benefits the overall reconnaissance of the fire scene. It can be divided into two directions: multi-source sensing based dangerous operation field information fusion, synchronous location and map construction; Autonomous navigation and localization of robots in dynamic and complex environments.

Hazardous explosive gas detection sensor. Prevent unknown casualties before firemen entering the scene by detecting and analyzing hazardous or explosive gas beforehand.

Figure 8-2 Hazardous Explosive Gas Detector

Fire extinguishment. (water cannon/liquid nitrogen)

Both water and foam cannon. The water cannon has a large flow rate and a long range. It can quickly switch the bloom/DC injection mode and the flow rate can be adjusted automatically.

Liquid nitrogen fire extinguishing can achieve the purpose of rapid cooling, rapid air isolation, and reduce the use of water.

Figure 8-1 Water Cannon

Smoke exhaust function. Smoke exhaust fan can exhaust smoke and dust, block thermal radiation, reduce smoke concentration and fire temperature to obtain a better field of view in the scene of fire for other devices to operate.

Figure 8-4 Smoke Exhaust Fan

Curtain wall/Automatic cooling system. To enhance the adaptability of the vehicle body to the ambient temperature of the fire field, equip the machine with a water curtain device or a water mist valve system to provide cooling protection, so that the robot can more effectively approach the fire source and fight the fire efficiently by cooling itself and isolating the fire source.

9. Conclusion

The objective of our project is to design and manufacture an intelligent fire reconnaissance robot that can be smoothly controlled remotely by firefighters to automatically detect the source of fire in both smoke and smoke-free environments in order to reduce casualties.

In the past three weeks, we have accomplished a lot. Firstly we specified our problem and clarified our design objectives. Then we studied some products on the market, analyzed the customer's needs, generated four concepts and eventually selected one as our final concept. We designed four modules: the camera module, ultrasonic sensor module, flame detection module, and movement module. After carrying out the manufacturing and testing of the products, we finished our prototype.

In conclusion, we achieved our objective statement. We finally realized all the functions we had set before and integrated them into a process. After many tests, our prototype has proven that it can efficiently explore a fire site and move smoothly in both smoke and smoke-free environments. We believe our project can assist firefighters in evaluating the various fire situation and making the best rescue plan to reduce the risk, which is very significant for reducing firefighter casualties nationwide.

We think our project deserves further development. The role of the ultrasonic module in pathfinding is limited since the environment may be complex, which means that it is still difficult to explore in a smoke environment. In the next stage, we will upgrade our ultrasonic sensor module with a new function that can draw and record topographic maps, which may improve practicability.

We learned a lot from the course. It was not limited to just making a small vehicle but a business plan, understanding the whole process of how a product is created, looking at the market side demand and making a product that meets the customer's needs. We also learn how to divide responsibilities and complete a project through teamwork. We benefited a lot from this course and enjoyed our time.

Acknowledgement

First and foremost, all of us in the group would like to extend our most sincere gratitude to our supervisors, Professor Francis Tay Eng hock and Professor Lu Weng Feng. We would like to thank them for their selfless teaching and meaningful advice. Without their professional guidance and kind encouragement and advice, I don't think we would have been able to complete our final product design so successfully. Professors Francis Tay Eng hock and Lu Weng Feng are honorable, responsible, and resourceful academics who have guided and inspired us at every stage of the product development process. The help they brought to us and the guidance they gave to our academic abilities had a profound impact not only on our ME4500 course but also on our future studies and research. We would like to express our deepest gratitude to them once again.

We shall extend our thanks to Ms. Wang Hui. Ms. Wang Hui funds the reimbursement and technical guidance of the laboratory, and she was very enthusiastic and patient in telling us about the whole process and the reimbursement at each step. For material and related parts of the requirements, Ms. Wang Hui secured a higher amount for us for the project, which allowed us to go through the whole process without any worries.

In addition, We shall express our thanks to Professor Zeng Kaiyang, Ms. Zhang Qin, and all the teachers who helped us with the development of the product for their kindness and assistance. They have also given us a lot of support in the process of designing our products. They have been a strong help in making the technology of our product a success in the end.

We would also like to express our sincere thanks to our team members in the A3 group, each of us participated in this project with great cooperation, and each member of the A3 group put their utmost enthusiasm, dedication, and seriousness into the design of the Intelligent Fire Reconnaissance Robot. Each team member gave their knowledge and time selflessly while doing their best work and actively helping other team members.

Last but not least, we would like to thank NUSRI and NUS for giving us an unforgettable and enjoyable course experience that will help us in our studies and research for the rest of our lives.

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Appendix

Code of movement control (Arduino)

```
#include <Servo.h>
#include <SoftwareSerial.h>

SoftwareSerial BT(A0, A1); // Pin0 为 RX 接 HC05 的 TXD    Pin1 为 TX 接 HC05
的 RXD

Servo myservo;   //定义舵机


int L1_IN1 = 7;int L1_IN2 = 8;int L1_ENA = 5;   //左前轮引脚定义

int R1_IN1 = 4;int R1_IN2 = 2;int R1_ENA = 3;   //右前轮引脚定义

int L2_IN1 = 12;int L2_IN2 = 13;int L2_ENA = 11;   //左后轮引脚定义

int R2_IN1 = 10;int R2_IN2 = 9;int R2_ENA = 6;   //右后轮引脚定义

void setup() {
  BT.begin(9600);   //开启蓝牙，波特率为 9600
   pinMode(L1_IN1,  OUTPUT);pinMode(L1_IN2,  OUTPUT);pinMode(L1_ENA,
OUTPUT);
   pinMode(R1_IN1,  OUTPUT);pinMode(R1_IN2,  OUTPUT);pinMode(R1_ENA,
OUTPUT);
   pinMode(L2_IN1,  OUTPUT);pinMode(L2_IN2,  OUTPUT);pinMode(L2_ENA,
OUTPUT);
   pinMode(R2_IN1,  OUTPUT);pinMode(R2_IN2,  OUTPUT);pinMode(R2_ENA,
OUTPUT); //设置引脚模式
  myservo.attach(A2);
  myservo.write(85);   //设置舵机初始角度
}

void L1_backward(int sp)//左前轮向后转
{
  digitalWrite(L1_IN1,LOW);
```

```
  digitalWrite(L1_IN2,HIGH);
  analogWrite(L1_ENA,sp);
}
void R1_backward(int sp)    //右前轮向后转
{
  digitalWrite(R1_IN1,HIGH);
  digitalWrite(R1_IN2,LOW);
  analogWrite(R1_ENA,sp);
}
void L2_backward(int sp)//左后轮后向后转
{
  digitalWrite(L2_IN1,HIGH);
  digitalWrite(L2_IN2,LOW);
  analogWrite(L2_ENA,sp);
}
void R2_backward(int sp)    //右后轮向后转
{
  digitalWrite(R2_IN1,HIGH);
  digitalWrite(R2_IN2,LOW);
  analogWrite(R2_ENA,sp);
}
void allstop()    //所有轮子停止运动
{
  digitalWrite(L1_IN1,LOW);
  digitalWrite(L1_IN2,LOW);
  digitalWrite(R1_IN1,LOW);
  digitalWrite(R1_IN2,LOW);
  digitalWrite(L2_IN1,LOW);
  digitalWrite(L2_IN2,LOW);
  digitalWrite(R2_IN1,LOW);
  digitalWrite(R2_IN2,LOW);
}
void L1_forward(int sp)    //左前轮向前转
{
  digitalWrite(L1_IN1,HIGH);
  digitalWrite(L1_IN2,LOW);
  analogWrite(L1_ENA,sp);
}
void R1_forward(int sp)    //右前轮向前转
```

```
{
  digitalWrite(R1_IN1,LOW);
  digitalWrite(R1_IN2,HIGH);
  analogWrite(R1_ENA,sp);
}
void L2_forward(int sp)    //左后轮向前转
{
  digitalWrite(L2_IN1,LOW);
  digitalWrite(L2_IN2,HIGH);
  analogWrite(L2_ENA,sp);
}
void R2_forward(int sp)    //右后轮向前转
{
  digitalWrite(R2_IN1,LOW);
  digitalWrite(R2_IN2,HIGH);
  analogWrite(R2_ENA,sp);
}

//控制函数
void control(int val) {
   switch(val){
     case 0:    //前进
     L1_forward(150);
     R1_forward(150);
     L2_forward(150);
     R2_forward(150);
     break;
     case 1:    //后退
     L1_backward(150);
     R1_backward(150);
     L2_backward(150);
     R2_backward(150);
     break;
     case 2:    //左平移
     L1_forward(150);
     R1_backward(133);
     L2_backward(133);
     R2_forward(150);
```

```
break;
case 3:   //右平移
L1_backward(150);
R1_forward(132);
L2_forward(132);
R2_backward(150);
break;
case 4:   //顺时针原地转圈
L1_forward(200);
R1_backward(200);
L2_forward(200);
R2_backward(200);
break;
case 5:   //停车
digitalWrite(L1_IN1,LOW);
digitalWrite(L1_IN2,LOW);
digitalWrite(R1_IN1,LOW);
digitalWrite(R1_IN2,LOW);
digitalWrite(L2_IN1,LOW);
digitalWrite(L2_IN2,LOW);
digitalWrite(R2_IN1,LOW);
digitalWrite(R2_IN2,LOW);
break;
case 6:   //逆时针原地转圈
L1_backward(200);
R1_forward(200);
L2_backward(200);
R2_forward(200);
break;
case 7:   //超声波模块向右转
myservo.write(5);
break;
case 8:   //超声波模块向左转
myservo.write(170);
break;
case 9:   //超声波模块归中
myservo.write(85);
```

```
    break;
    }
}

//主函数
void loop(){
  if (BT.available()){
   char val = BT.read();
   BT.println(val-48);
   control(val-48);
  }

}
```

Code of flame sensor & ultrasonic module (Arduino)

```
#include <SoftwareSerial.h>
#define PIN_TRIG 3    //超声波模块引脚定义

#define PIN_ECHO 4    //超声波模块引脚定义


const int digitalInPin1=A0;    //左路火焰传感器引脚定义

const int digitalInPin2=A3;    //中路火焰传感器引脚定义

const int digitalInPin3=A7;    //右路火焰传感器引脚定义

double DISTANCE;    //超声波模块输出
SoftwareSerial BT(5,6);

void setup()
{
  pinMode(digitalInPin1,INPUT);
  pinMode(digitalInPin2,INPUT);
  pinMode(digitalInPin3,INPUT);    //定义引脚模式

  pinMode(PIN_TRIG, OUTPUT);     //超声波模块引脚定义

  pinMode(PIN_ECHO, INPUT);     //超声波模块引脚定义

  BT.begin(9600);
```

```
}

//超声波模块测距函数
void get_distance(){
    digitalWrite(PIN_TRIG, HIGH);
    delayMicroseconds(10);
    digitalWrite(PIN_TRIG, LOW);

    double duration = pulseIn(PIN_ECHO, HIGH);
    double distance= duration/58;
    DISTANCE = distance;

}

//超声波模块蓝牙通信函数
void ultrasonic()
{
  get_distance();
  BT.print("Obstacle ");
  BT.print(DISTANCE);
  BT.println("cm ahead");
}

//火焰检测蓝牙通信函数
void firedetect(){
if
((analogRead(A0)>analogRead(A3))&&(analogRead(A0)>analogRead(A7))&&(anal
ogRead(A0)>30)&&(analogRead(A0)<780)){
     BT.print ("The fire is on the left front, distance:");
BT.println
((-0.00000000003035793839)*analogRead(A0)*analogRead(A0)*analogRead(A0)*a
nalogRead(A0)*analogRead(A0)+
(0.00000006508935755135)*analogRead(A0)*analogRead(A0)*analogRead(A0)*an
alogRead(A0)+(-0.00005179515989422112)*analogRead(A0)*analogRead(A0)*anal
ogRead(A0)+0.018900176116564565*analogRead(A0)*analogRead(A0)+(-3.198140
1354342127)*analogRead(A0)+247.3049576981166);
     BT.println("cm");
     }
if
((analogRead(A3)>analogRead(A0))&&(analogRead(A3)>analogRead(A7))&&(anal
ogRead(A3)>30)&&(analogRead(A3)<780)){
```

```
  BT.print ("The fire is straight ahead, distance:");
BT.print ((-0.0000000003035793839)*analogRead(A3)*analogRead(A3)*analogRead(A3)*analogRead(A3)*analogRead(A3)+ (0.0000006508935755135)*analogRead(A3)*analogRead(A3)*analogRead(A3)*analogRead(A3)+(-0.000517951598942211 2)*analogRead(A3)*analogRead(A3)*analogRead(A3)+0.01890017611656456 5*analogRead(A3)*analogRead(A3)+(-3.1981401354342127)*analogRead(A3)+247.3049576981166);
     BT.println("cm");
     }
if ((analogRead(A7)>analogRead(A0))&&(analogRead(A7)>analogRead(A3))&&(analogRead(A7)>30)&&(analogRead(A7)<780)){
  BT.print ("The fire is on the right front, distance:");
BT.print ((-0.0000000003035793839)*analogRead(A7)*analogRead(A7)*analogRead(A7)*analogRead(A7)*analogRead(A7)+ (0.0000006508935755135)*analogRead(A7)*analogRead(A7)*analogRead(A7)*analogRead(A7)+(-0.000517951598942211 2)*analogRead(A7)*analogRead(A7)*analogRead(A7)+0.01890017611656456 5*analogRead(A7)*analogRead(A7)+(-3.1981401354342127)*analogRead(A7)+247.3049576981166);
     BT.println("cm");
     }
  else {
  BT.print("No fire was detected");
  }
}

//主函数

void loop(){
ultrasonic();
firedetect();
delay(1000);   //一秒发送一次数据
}
```

Code of Flame distance fitting (MATLAB)

```
import pandas as pd
from matplotlib import pyplot as plt
import numpy as np
```

```
data=pd.read_csv('火焰数据 1.csv')

#data 赋值

x=data.loc[0:179,'x']
y=data.loc[0:179,'y']
plt.figure(figsize=(10,5))
plt.scatter(x,y)
plt.show
x=np.array(x)
x=x.reshape(-1,1)
y=np.array(y)
y=y.reshape(-1,1)
from sklearn.preprocessing import PolynomialFeatures

poly = PolynomialFeatures(degree=5) #增加 X^2 特征

poly.fit(x)

x2 = poly.transform(x)# 对 X 进行转换

from sklearn.linear_model import LinearRegression
pr = LinearRegression()
pr.fit(x2,y)
y_predict = pr.predict(x2)
from sklearn.metrics import mean_squared_error,r2_score
import math
MSE_pr= mean_squared_error(y, y_predict)
RMSE = math.sqrt(MSE_pr)
print(RMSE)
fig, ax = plt.subplots(1, figsize=(12, 5))
ax.set(xlabel='Analog', ylabel='Distance')
ax.scatter(x,y,color='teal',edgecolor='black',label='Original Data',marker='^')
ax.plot(x,y_predict,color='orange',label='Predict Data')
plt.title('Flame Distance Simulation Model')
plt.xlim(0,800)
plt.legend()
plt.show()
np.set_printoptions(suppress=True,precision=20)
print(pr.coef_)
Prin(pr.intercept_)
```