SCHOOL OF ADVANCED TECHNOLOGY
DEPARTMENT OF MECHATRONICS AND ROBOTICS

MEC202 INDUSTRIAL AWARENESS AND GROUP PROJECT

Group Project Report: Localisation of Robots

Group : 28

Group Member : Yiliin.Cao 2034189
Jifeng.Li 2035919
Zhiyang.Zhao 2035981
Yilin.Yang 2036145
Yihan Lu 2036641

Email Adress : Yilin.Cao20@student.xjtlu.edu.cn
Jifeng.Li20@student.xjtlu.edu.cn
Zhiyan.Zhao20@student.xjtlu.edu.cn
Yilin.Yang20@student.xjtlu.edu.cn
Yihan.Lu20@student.xjtlu.edu.cn

Supervisor : Xinheng Wang

Abstract

This report demonstrates on a smart robot which undertakes the function on locating and mapping. To fulfill the requirement of the application in the train stations and airports navigation, the smart robot should be able to find its location, plan the route from the map and give out the navigation suggestions. The deeper application need of the robot is related to the obstacle avoidance control, the precision of the mapping as well as the motor system control. Based on the survey and experience from the specialist, it is found that the sensors including the ultrasonic sensor, infrared sensor and lidar can be used to determine the location, the proper software application should be loaded to help draw the map and a screen is to give out the navigation suggestions. Generally, the location function, ultrasonic obstacle avoidance function, mapping, navigation function have been achieved. As the basic modules, LiDAR should be loaded on the smart robot. The result shows, compared to other navigation smart robots, it concentrates on more functions implement. And for the better satisfaction to the customers, it dedicates to the privacy and security.

1. Introduction

1.1 Description

With the modern airport and train stations have become more complex and larger, airport navigation is a critical facet which has been attached with importance. One such application is the navigation smart robot, whose features designed to be easy to use, safe and reliable, and equipped with a range of advanced features, has made it become an indispensable part of the modern airport experience. The airport navigation robot is typically a self-driving vehicle which is capable to lead the passengers to their destination. The robot is equipped with sensors and cameras that allow it to navigate its environment safely and efficiently, and it is also designed to be easy to operate. The passengers simply enter their destination and the robot takes them there. However, most navigation robots are weak in their Simultaneous Localization And Mapping(SLAM), which means they can not adapt to a new airport without an already existed map. From the feature of the mapping, an new application of the robot car to rescue in the unfamiliar environment is considered as well. Thus, the method to SLAM has been considered as an important part in this project to make the smart robot be able to learn to navigate through new airports and adapt to changes in the environment by analyzing data from its sensors and LiDAR, making it an even more intelligent and efficient vehicle. Compared to other SLAM methods, LiDAR SLAM is the perfect and most convenient choice[1]. The other problem is about the safety worry from the designers. One solution given out from this project is to add surplus sensors to ensure the situations around the robot, and update the control algorithm to complete the obstacle avoidance system. In addition to LiDAR, the airport navigation robot in this project is also equipped with cameras that use YOLO V5 to recognize people and objects in its environment. This feature enables the robot to have a better understanding of its surroundings, and to avoid potential obstacles or hazards. By combining LiDAR and camera data, the robot can create a more accurate map of its environment, making it easier for it to navigate through new airports and adapt to changes in the environment. The integration of YOLO V5 also adds an extra level of safety to the robot, ensuring that it can avoid collisions with both objects and people[2].

In this report, survey subjects are mainly from students in university, who give feedback on the following parts including the SLAM methods they prefer, the worries about the smart robot, the energy consumption and the cost of the robot, which will be introduced in the subsequent part in this section. Section 2 will concentrate on the comparison of different design ideas and functions implementation. The concrete design including circuit design, prototyping and testing will be demonstrated in the section 3. Section 4 is the general conclusion. Finally, several appendices have been included to enhance the comprehensiveness of the report and provide supplementary information.

1.2 Survey

The survey results will contribute to our report on navigation robots, providing valuable information on the potential demand for such robots and their potential benefits in enhancing the travel experience.

1.2.1 Market need and customer-requirements

The purpose of conducting following questions was to gain insight into the market and students' usage and specific requirements for navigation robots in airports and train stations. The questionnaire results revealed that the majority of respondents deemed such robots necessary, with most users reporting that the robots were helpful. There are three questions set for this part.

a. Do you think you'll need a navigation robot?

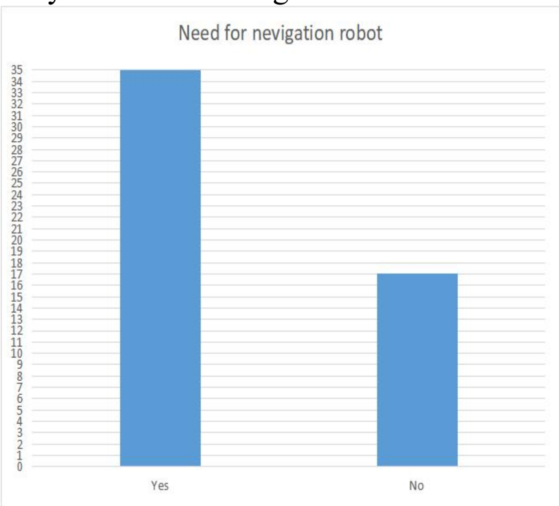


Figure 1: Need for navigation robot.

b. Did the navigation robot you encountered work well?

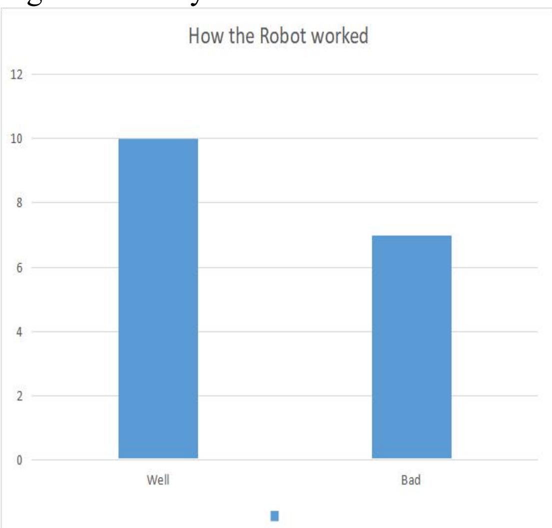


Figure 2: Evaluation of the experienced robots.

c. Have you ever encountered a navigation robot at an airport/train station or anywhere else?

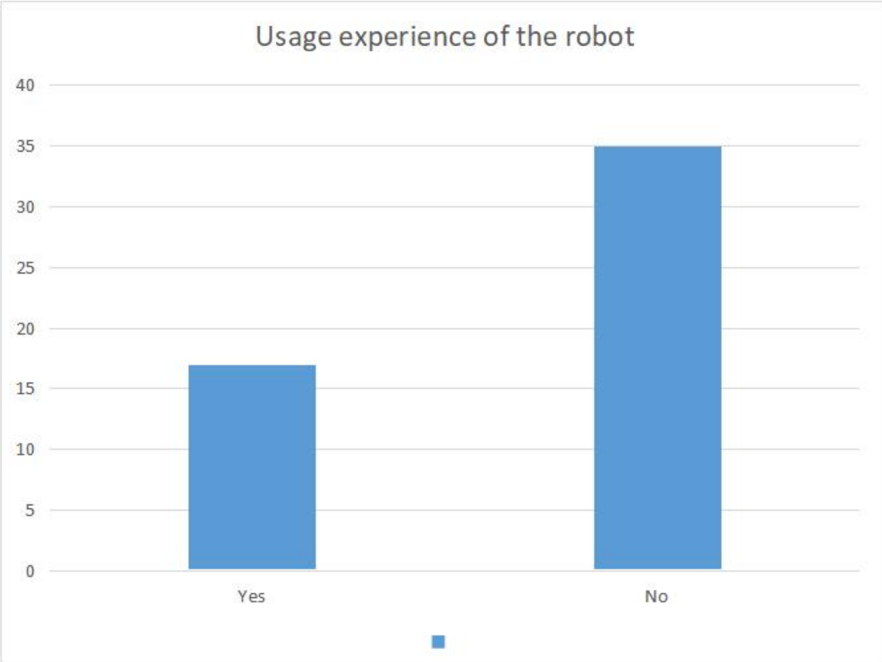


Figure 3: Usage experience of the robot.

The questionnaire results revealed that the majority of respondents deemed such robots necessary, with most users reporting that the robots were helpful.

1.2.2 Suggestions from the survey

As the item dedicates to the navigation, problems related to the facets about the main functions and improvements are put into the survey for better adaption to the market. The market survey results are mainly collected from the university students.

a. Do you want a navigation robot to take you to your destination/show you how to get there?

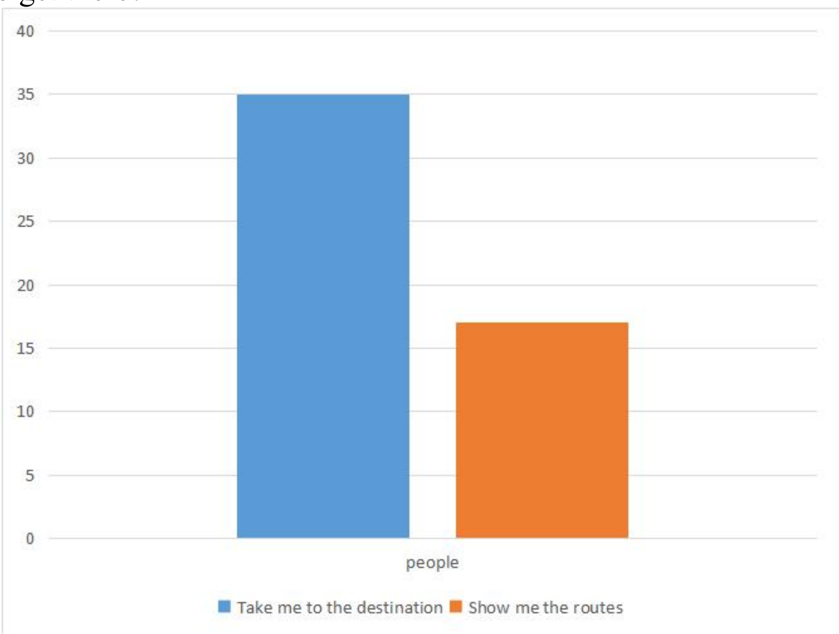


Figure 4: comment on the survey methods.

b. Which aspect of navigation robot do you prefer to have the most outstanding advantage?

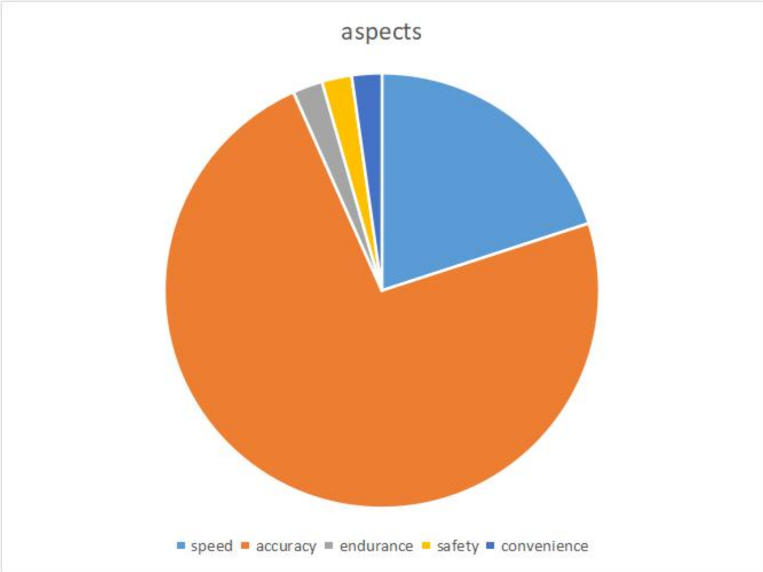


Figure 5: Suggestions to the robot.

Based on the collected suggestions regarding the navigation robots, some of the key areas for improvement include increasing the precision of the robot's instructions, providing more human-like guidance and simplifying the user experience.

1.2.3 Survey Findings: Informing the Next Steps of Our Experiment

The information from the questionnaire indicates the directions for the robots to develop.

As 63.46% of the interviewees suggest the importance of the precision, it is considered to improve the precision of the robot's instructions to satisfy the requirements. Some suggestions from 3 interviewees especially indicated providing real-time updates on changes in gate or platform numbers, as well as better integration with the airport or train station's scheduling system. This would ensure that users receive accurate and up-to-date information and can make their way to their destination smoothly.

One comment from the interviewees has been mentioned that the guidance he received from the navigation robot is too formulaic. To provide more human-like guidance, respondents suggested incorporating natural language processing capabilities, allowing the robot to understand and respond to user questions and requests in a more conversational manner. Additionally, the robot could be programmed to adjust its communication style based on the user's tone and mood, making the interaction more personalized and engaging.

41.1% of the interviewees have thought that the interactivity method is inconvenient for them. To simplify the user experience, suggestions included incorporating voice recognition, touchscreens, and other intuitive interfaces, making it easier for users to interact with the robot. Additionally, providing clear and concise instructions, as well as visual aids such as maps and diagrams, would help users navigate the airport or train station with greater ease and confidence.

1.3 Simultaneous Localization and Mapping

Simultaneous Localization and Mapping (SLAM) is a critical module for navigation robots, enabling them to accurately determine their location and map their surroundings in real-time [3]. This module uses sensor data from various sources, such as cameras, lidar, and odometry sensors, to generate a map of the environment and estimate the robot's position within that map [4]. By continuously updating the map and position estimate, the robot can navigate through complex environments with greater accuracy and efficiency. SLAM is a fundamental component that underpins the functionality of navigation robots and is essential for providing users with reliable and effective guidance [5].

1.4 LiDAR

According to Kaushal and Garg [6], LiDAR, which stands for Light Detection and Ranging, is a remote sensing technology that uses laser pulses to measure the distance to objects. In the context of the intelligent airport navigation system, LiDAR is used to provide accurate 3D mapping of the environment and to detect obstacles, which is essential for safe navigation of the small vehicle. The LiDAR sensor emits a laser beam that bounces off objects in the environment, and the time it takes for the beam to return is used to calculate the distance to the object. This allows the LiDAR to create a high-resolution map of the environment in real-time, which is used to guide the navigation of the small vehicle. LiDAR technology has become an increasingly popular choice for autonomous systems due to its high accuracy and reliability.

1.5 Ultrasonic and infrared sensors

The airport/train station navigation robot is equipped with both infrared and ultrasonic sensors for obstacle avoidance. The infrared sensor emits infrared radiation to detect nearby objects and measures the reflection to determine the distance to the object [7]. On the other hand, the ultrasonic sensor emits high-frequency sound waves and measures the echo to detect objects at a greater distance [8]. The obstacle avoidance system uses a combination of these sensors to make accurate decisions and adjust the robot's path accordingly. By integrating these sensors, the robot can navigate safely through the airport/train station environment with minimal human intervention.

2. Design Concept Comparison, Development and Screening

2.1 System design

In this system, a computer is used to control two Raspberry Pi motherboards. On the computer side, a virtual network control (VNC) is to connect to the Raspberry Pi.

For the Raspberry Pi A, an installed Ubuntu on it deploys the Robot Control System (ROS). Then it can be used to control the camera and LIDAR for visual recognition and SLAM respectively, and save the files locally and transfer them to our PC later.

Next, these results are able to be sent as a command to Raspberry Pi B. With the official Raspberry Pi system installed on Raspberry Pi B, the code can be used to control the driver board directly and further control a range of functions including infrared obstacle avoidance, ultrasonic alerts and basic motion control.

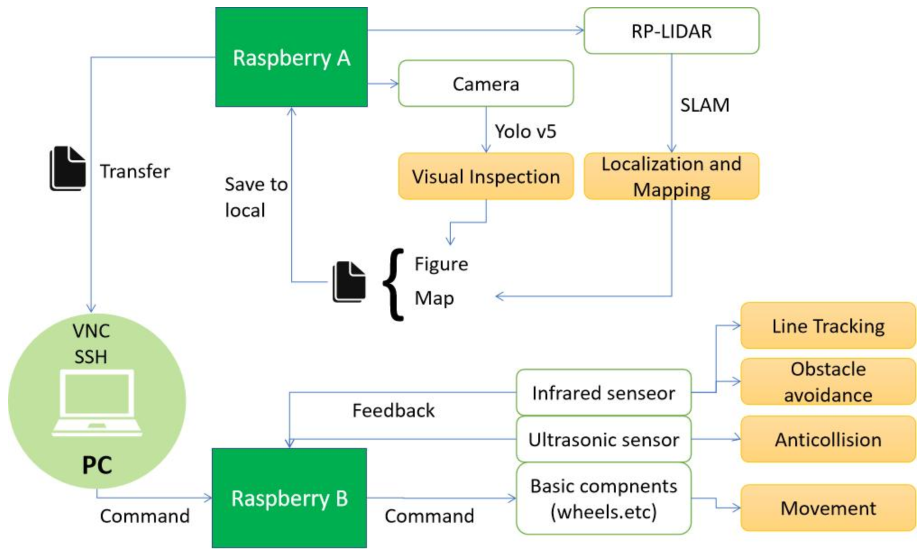


Figure 6: System structure.

2.2 Selected concepts after comparison

2.1.1 Localization

We decide to use LiDAR to implement simultaneous localization and mapping(SLAM), which describes the scenario where the robot moves from an unknown position in an unknown environment, and locates itself according to the position and the map during the movement. At the same time, an incremental map is built on the basis of its own positioning to realize autonomous positioning and navigation of the robot.This technology can make the localization of robot faster, more accurate and intuitive. Compared to other implementation methods including feature-based visual SLAM[9],direct visual SLAM[10] and RGB-D based visual SLAM[11], LiDAR SLAM is component to overcome the difficulties such as light effect, the expensive cost and limited application environment.

2.1.2 Obstacle Avoidance

Infrared sensor is the final choice to implement the obstacle avoidance. Compared to other sensors, it works with high precision and sensitivity. Otherwise, they are immune to ambient light interference. It means they can work in difficult environment. Additionally, the size of the sensor is be able to be easily integrated into small devices or robots, such as the smart car.

3. Prototyping and testing

3.2 Prototyping

3.1.1 Robot assembly

During the assembly of the robot, we follow the steps in the tutorials from manufacturers, and make some improvements at the end. We firstly assemble the bottom of the car, which include wheels and motors. Then we start to assemble the parts on the top board of the robot, the order of assembly is Raspberry Pi board, control board, infrared obstacle avoidance, infrared tracking, radar base, power supply, ultrasonic transmitter and camera. We changed many devices' positions in this part. First of all, we replaced the original equipment with sharper cameras and more sensitive radars. In order to get a clear map, we raised the base of the radar and moved the Raspberry Pi board back to provide more space for the radar. Next, we use 2 Raspberry Pi boards, one is for basic movement and another is for radar and camera, so that the car could perform better.

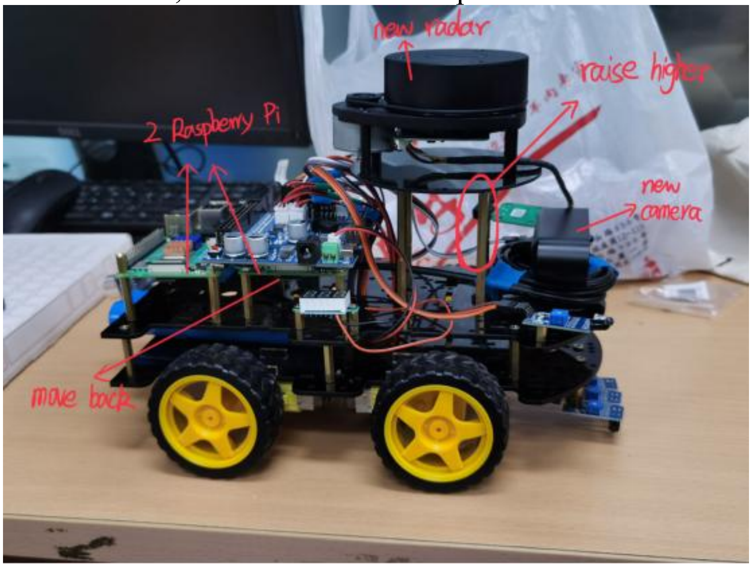


Figure 7: Structure of the smart car.

3.1.2 Raspberry

Our team has chosen to use the Raspberry Pi 4B as the motherboard for our robot design. This single board computer offers numerous advantages, including a large number of interfaces and expandable capabilities. Using this technology, we have implemented VNC and SSH for remote control. The VNC application allows us to remotely control the graphical interface of the Raspberry Pi system, providing us with a seamless connection to the robot. By connecting the Raspberry Pi and master computer to the same local area network, we can use the Raspberry Pi's IPV4 address to establish a connection.

SSH, on the other hand, is a widely-used Linux protocol that allows us to securely transmit files from the computer to the Raspberry Pi and load configuration files into the system. This encrypted connection protocol provides an additional layer of security during sign-in and prevents unauthorized access to the virtual machine. However, even with SSH, using a password for an SSH connection can still make the VM vulnerable to brute force attacks. To mitigate this risk, we use a public-private key pair, also known as an SSH key, to connect to the VM. The public key is stored in the VM and the private key is stored in the computer's local system. This allows the VM to verify the private key using the public key in the Raspberry Pi, ensuring a secure and reliable connection. With these tools, we are able to remotely program, debug, and control the robot with ease.

3.1.3 Simultaneous Localization and Mapping (SLAM)

The LIDAR we use is RP LIDAR A1 and its specifications can be viewed in Appendix A. The advantage of this radar is that it is self-rotating and stable. We put this LIDAR on the high table of the robot to avoid other elements blocking the scanning signal.

To get the best out of LIDAR and to configure the relevant files, we first install the Ubuntu virtual machine on the Raspberry and then install the Robot Operating System (ROS).

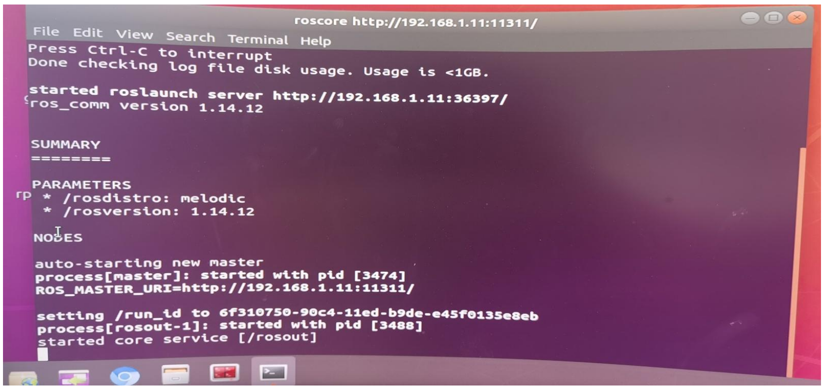


Figure 8: Robot Operating System(ROS).

Then we decide to use hector slam. The strengths of this algorithm are its real time and robustness, and its excellent performance in dealing with high speed, dynamic environments. We use the software RVIZ to display the point cloud data we have collected with LIDAR.

Figure 9: Rough SLAM result.

Using the collected point cloud data to generate a local map and fusing the local map with the global map, we can build a map using a raster map. Using the Gaussian Newton method, the odometer information is estimated directly using LiDAR so that it can show its position in the global map and reach Localization.

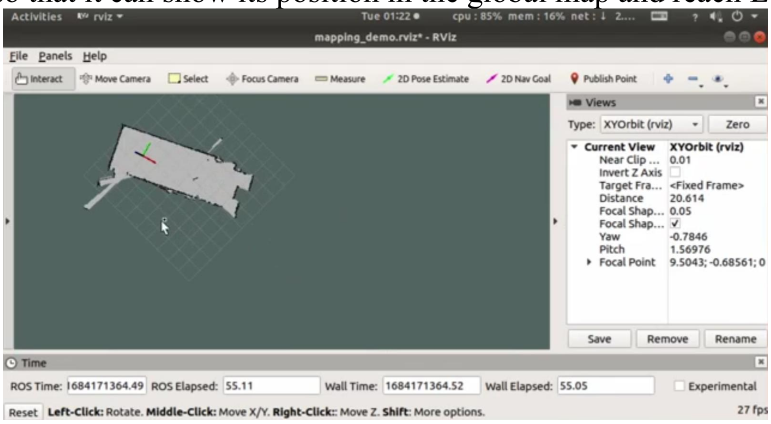


Figure 10: The final SLAM result.

Since the robot's Raspberry Pi motherboard can be connected wirelessly to the computer via WIFI, the map can be transferred to the computer for viewing in real time after it has been built. In this way we can achieve robot localisation.

3.1.4 Camera visual inspection

The system uses camorama software to get the capture camera footage. The software supports 2K resolution video recording and photo taking as well as high speed transmission. This design allows the driver to clearly see the environment in front of the car in real time from a remote location and make a judgment on the next movement.

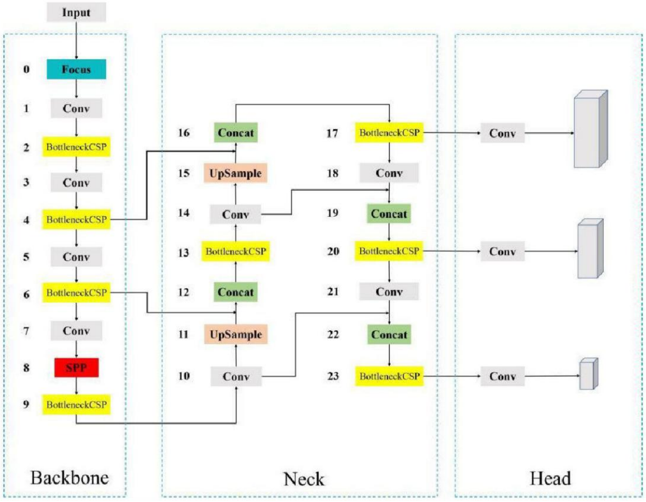


Figure 11: Data structure.

Another aspect of the vision design is the inclusion of a target detection module. This module uses a deep neural network model, YoloV5s, and it uses a pre-trained model to record video and detect targets in real time from the captured images in the camera. The inference speed of the model is faster than that of the fourth generation model, while satisfying subsequent rapid deployment using the Openvino or TensorRT frameworks. It facilitates future iterations of this algorithm module. In addition, a large amount of data including video and images can be obtained using this algorithm, which is suitable for applications in special scenarios. Such data collection also supports future personalized deployments.

Figure 12: Visual recognition.

3.1.5 Basic movement of robot and obstacle avoidance

This part focuses on the basic movement of the robot consisting of Infrared obstacle avoidance, ultrasonic warning and control system on computer. Each functionality has been shown in the plot, we can see that infrared obstacle avoidance can away from the obstacles in both sides then change the movement mode to avoid collision.

As to the ultrasonic warning, it can take in the duration between transmission time and echo time, which can be used to calculate the distance between obstacle and robot. If the distance is under the safe distance, it will warm us that there is something in the behind of robot then we can use this characteristic to manipulate robot to avoid collision.

Besides, the control system, which is operated through keyboard inputs, allows for remote manipulation of the robot's movements. This feature is particularly useful for situations where it may not be safe for a human to be in close proximity to the robot, such as in hazardous environments or areas with limited accessibility.

Furthermore, the robot is equipped with a tracking code that allows it to move in accordance with the dark line on the ground. This feature adds an extra layer of precision to the robot's movements, ensuring that it can navigate through complex environments with ease.

These four functions construct a robust robot to deal with some tricky problems, such as it can use infrared obstacle avoidance to decrease the collision and let it can correct the direction automatically, which can be used as emergency avoidance obstacle system to tackle sudden danger obstacle, owing to the infrared sensor is definitively sensitive to the distance between robot and obstacle. Besides, the ultrasonic warning can be used to detect the danger behind the robot and show the distance between them, which can show the real-time reaction to the operator of the current situation behind the robot. After that, the control system can let the user use the keyboard to control the robot movement, which can let users can remotely to manipulate the robot.

For further consideration, the camera added to the robot enables it to capture and transmit real-time video feed of its surroundings to the user. This can be particularly useful in situations where the user cannot physically be present to operate the robot, but still needs to monitor its movements.

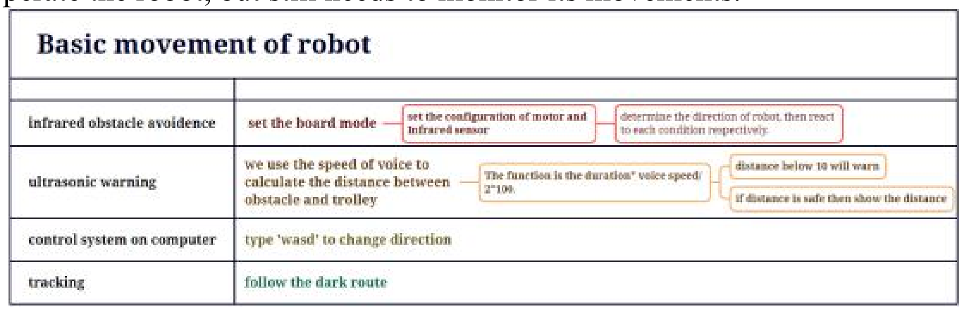


Figure 13: Basic movement.

Applying this system, we can let the robot receive operator instructions in real time to complete tasks, and can go deep into dangerous places or places that are difficult for people to reach to complete some search and rescue tasks. Finally, the tracking system can be used to follow the prescribed trajectory to complete some simple tasks that have been planned. All of them is operated on the SSH and VNC protocol mechanism.

3.2 Testing

3.2.1 Basic Motion Module

In this module, it is to test the moving module of the smart car. As the command like "w" with "Enter" input into the control unit from the computer, the car was able to go straightly in one direction. And when "a" or "d" with "Enter" were input, the car was able to turn left or turn right. Additionally, the car would go straightly opposite from the direction of "w", when "d" was input. However, when testing the motion module, it was found that the original rate of the velocity was low and it was solved by modifying the code. The speed became normal after doing that.

Thus, the testing shows that the motion module of the smart car works.

3.2.2 Obstacle Avoidance Module

As the HC-SR04 Ultrasonic Sensor is able to detect the distance from the car to the obstacle, it provides the car with ability of obstacle avoidance. When testing, it was shown that the warning would display in the monitor as the car was approaching to the obstacle and showed the distance to the obstacle.

Figure 14: Warning.

As for infrared sensor contributing to the obstacle avoidance module, it is designed by the code to detour the obstacles automatically when recognizing the obstacle. In the test, when the infrared sensor which is set on the right front of the car recognized the obstacle, the car will detour it by turning left and going straight. Similarly, when the sensor on the left front of the car recognized the item, it would turn left and go straight.

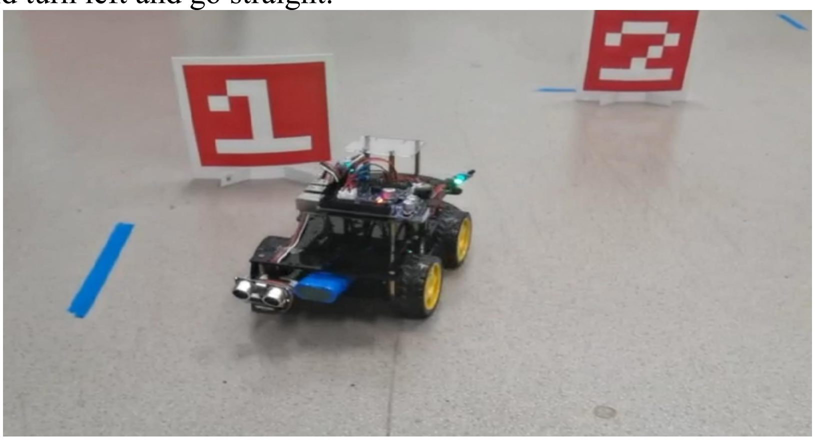


Figure 15: Obstacle Avoidance

3.2.3 Camera Test

The camera loaded on the car is to provide the operator with a view for the remote control, and the built-in algorithm enables the car to recognize people as well as the kinds of the items. During the test, through the monitoring window in the computer, it was found that the picture was clear. Additionally, the recognition function was successful with some delay.

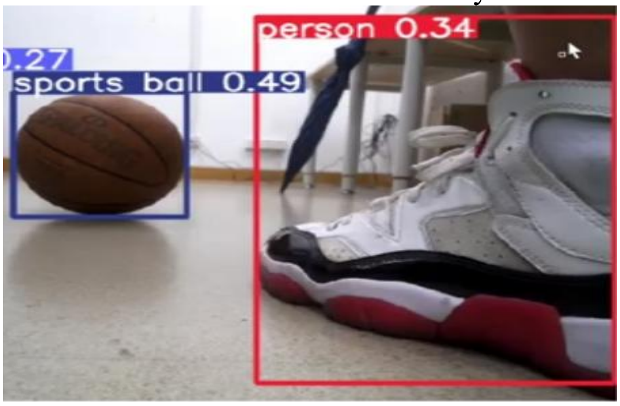


Figure 16: Camera Visual Inspection.

3.2.4 SLAM Module

In this project, the SLAM module is designed to create a current map by scanning the surrounded environment using the LIDAR. The test is to put the car into a unfamiliar environment and examine whether the map can be generated. Through the test, it was found that the map was able to created as the car repeated the routes 2-3 times.And with more times and periods the car acted, the map created would be more precious.

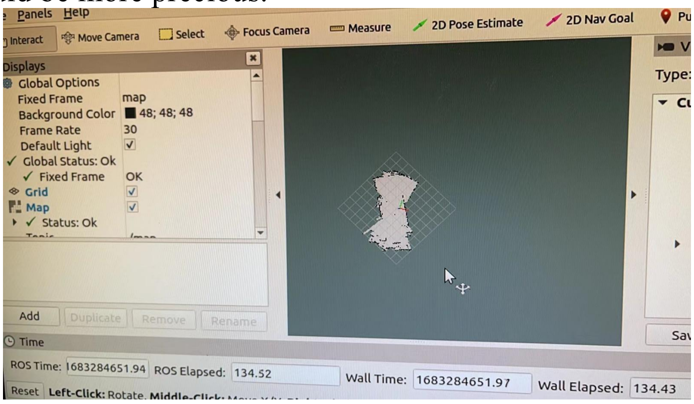


Figure 17: Map in proceeding.

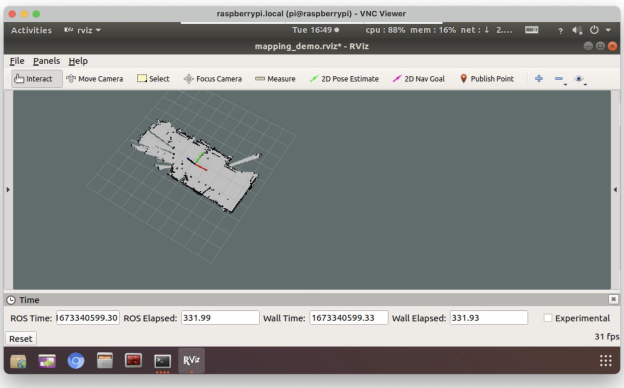


Figure 18: Completed map.

3.3 Discussion

3.3.1 User Experience Feedback

The feedback from the users offers suggestions for current corrections and future improvement. Totally, the suggestions concentrate on roughly three points including complex operation, unintelligent and unstable connections.

According to the complex operation, the robot is originally designed as a robot integrated with diversified functions. However, the functions haven't been combined in the most effective way. As the functions should be used in different operation modules, the operation shows complex.

Regarding to the unintelligent comment, the interactivity between the operators and the car is still rough. Although the command window offers a page to manipulator to operate, operations are difficult to be input and carried out. It suggests that the command input method should be simplified and different interactions can be considered.

Unstable connection is related to the WIFI module of the Raspberry Pi. As the WIFI does not work stable, the connection between the Raspberry and the computer through the WIFI is unstable as well.

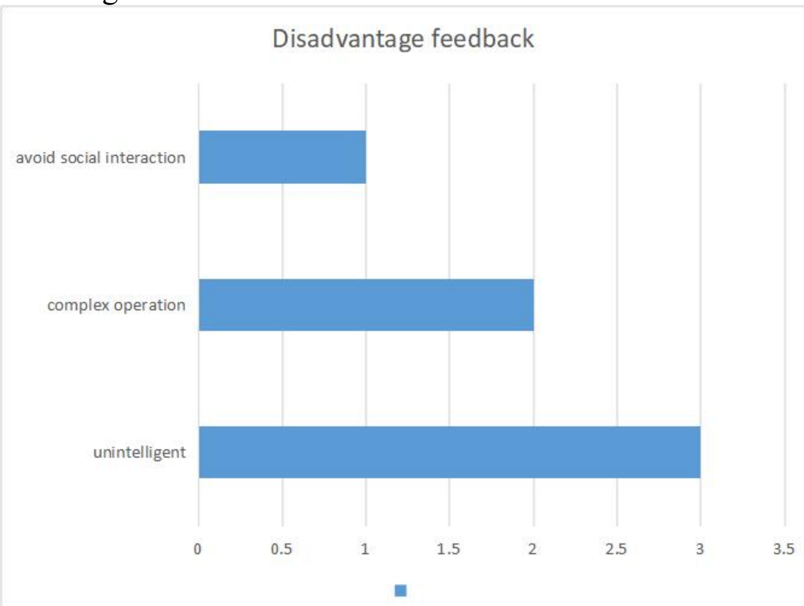


Figure 19: Disadvantages feedback.

3.3.2 Difficulties and Solutions

a) About Raspberry Pi

We met several problems when we use Raspberry. Firstly, in order to implement visual recognition and SLAM, we needed to install ROS on Ubuntu, but encountered problems due to system incompatibility and limited interfaces. So we used two Raspberry Pi's, one with Ubuntu installed to serve the camera and LIDAR and one using the original Raspberry Pi system to control the driver board and further control infrared sensors, ultrasound sensors and wheels.

In addition, the hotspot service provided by the Raspberry Pi itself is very unstable. We have researched and found that it may be related to power supply stability and hardware temperature. So we configured an additional rechargeable battery and heat sink. We also later changed the connection mode from a hotspot connection based on the Raspberry Pi itself to using a

LAN connection, which improved the convenience and stability of the wireless connection

b) About camera

When the algorithm calls the camera, there is a possibility that the camera profile will not be found. So when we start the algorithm, check the system device configuration file directory and find that the configuration file name will be tampered with. Then you need to determine the configuration file call path, and the algorithm can run normally.

c) About robot assembly

1.The base of the radar is not high enough, making it vulnerable to other devices on the vehicle when plotting.

Solution: Add copper pillars under the base of the radar to increase the height of the radar.

2.The installation of the radar is not stable enough.

Solution: Cut a Raspberry Pi plate and mount the four bottom corners of the radar on an acrylic plate, after which it is mounted on a copper column.

3.After adding the power bank, the movement speed of the trolley is too slow.

Solution: Change the parameters of the trolley motion module, adjust the power to become larger, so that it can move forward normally.

4.Encountered infrared sensor failure.

Solution: After debugging the sensitivity several times, we found that the infrared sensor in front left failed, and we replaced it with a new infrared sensor.

3.3.3 Applications and Future Work

In application scenario, this small car can navigate and locate itself in unfamiliar environments, and provide a visual display of the environment through mapping. It also supports obstacle avoidance to traverse complex terrain and visual inspection for recognition and search.

Some suggestions from the feedback indicate that the dimension of the data collection is simple. The 2D SLAM result is limited especially for rescue situation. Also, two boards which perform different functions have been loaded on the car. Two boards with their data are redundant which make the whole system inefficient.

Moving on to future work, following the suggestions from the feedback is on the one hand. Thus, we plan to upgrade the SLAM system by using a 3D-LIDAR to collect more information. Combining two boards into one and simplifying the data structure are scheduled as well. On the other hand, it is planned to upgrade the battery to provide a more stable voltage and enhance the signal strength to improve connection stability. Additionally, a voice module to improve interactivity is to added by upgrading the buzzer, and universal wheels or other structures loaded to the car will make the car adapt to more complex environments such as destruction, which will benefit the application in rescue situations.

After the prototype becomes the end product, it can be promoted to airports, train stations and any other complicated circumstances to fill up with the requirement of the customers. And it will give help to rescue actions especially in the unfamiliar environments for its SLAM function.

4. Conclusion

The design of a smart robot for airport navigation is an important and innovative project that has the potential to revolutionize the airport experience for passengers. This project focuses on using LiDAR SLAM and surplus sensors to ensure the safety and efficiency of the robot, and to enable it to learn to navigate new airports and adapt to changes in the environment.

From a perspective of equality, diversity, and inclusivity, this project has the potential to benefit a wide range of airport passengers, including those with disabilities or limited mobility. By providing a safe and reliable navigation experience, this smart robot can help to create a more equal and accessible airport environment.

Considering benefits of this project, the smart robot is expected to improve airport navigation efficiency, reduce the need for human assistance, and provide a more personalized and convenient experience for passengers. This can lead to increased customer satisfaction and loyalty, and ultimately result in a positive impact on the airport industry.

In terms of responsibility, the designers have taken into account the safety concerns and have added surplus sensors and updated the control algorithm to complete the obstacle avoidance system. This shows commitment to responsible design and ensuring the safety of passengers.

In conclusion, the design of a smart robot for airport navigation using LiDAR SLAM and surplus sensors is an innovative and promising project that has the potential to improve airport navigation efficiency and create a more equal and accessible airport environment. The use of LiDAR SLAM and surplus sensors not only ensures the safety of passengers but also enables the robot to learn to navigate new airports and adapt to changes in the environment.

However, it is important to consider the potential impact on employment in the airport industry if the product is widely put into production, as the use of robots for navigation may reduce the need for human assistance. It is important to ensure that the implementation of this technology is done in a responsible and ethical manner, taking into consideration the potential for inequality.

Overall, the design of a smart robot for airport navigation is a positive step towards creating a more efficient, safe, and personalized airport experience for passengers. It is important to continue to develop and refine this technology in a responsible and inclusive manner, with a focus on creating a more equal and accessible airport environment for all passengers.

Reference

[1] Z. Chen, Y. Qi, S. Zhong, D. Feng, Q. Chen and H. Chen, "SCL-SLAM: A Scan Context-enabled LiDAR SLAM Using Factor Graph-Based Optimization," 2022 IEEE International Conference on Unmanned Systems (ICUS), Guangzhou, China, 2022, pp. 1264-1269, doi: 10.1109/ICUS55513.2022.9987005.

[2] L. Xiaomeng, F. Jun and C. Peng, "Vehicle Detection in Traffic Monitoring Scenes Based on Improved YOLOV5s," 2022 International Conference on Computer Engineering and Artificial Intelligence (ICCEAI), Shijiazhuang, China, 2022, pp. 467-471, doi: 10.1109/ICCEAI55464.2022.00103.

[3] H. Durrant-Whyte and T. Bailey, "Simultaneous localization and mapping: Part I," in IEEE Robotics & Automation Magazine, vol. 13, no. 2, pp. 99-110, June 2006, doi: 10.1109/MRA.2006.1638022.

[4] S. Thrun, W. Burgard and D. Fox, Probabilistic Robotics (Intelligent Robotics and Autonomous Agents series). MIT Press, 2005.

[5] P. Newman and K. Ho, "Guest Editorial: Special Issue on Simultaneous Localization and Mapping," in Journal of Field Robotics, vol. 23, no. 8, pp. 587-588, Aug. 2006, doi: 10.1002/rob.20166.

[6] R. Kaushal and N. Garg, "A review on LiDAR technology: Its principles, working, and applications," in Measurement and Control, vol. 54, no. 1-2, pp. 41-51, 2021, doi: 10.1177/0020294021993076.

[7] Y. Zhang and W. Liu, "Obstacle avoidance of mobile robot based on infrared and ultrasonic sensors," in International Journal of Advanced Robotic Systems, vol. 15, no. 2, pp. 1-9, 2018, doi: 10.1177/1729881418768090.

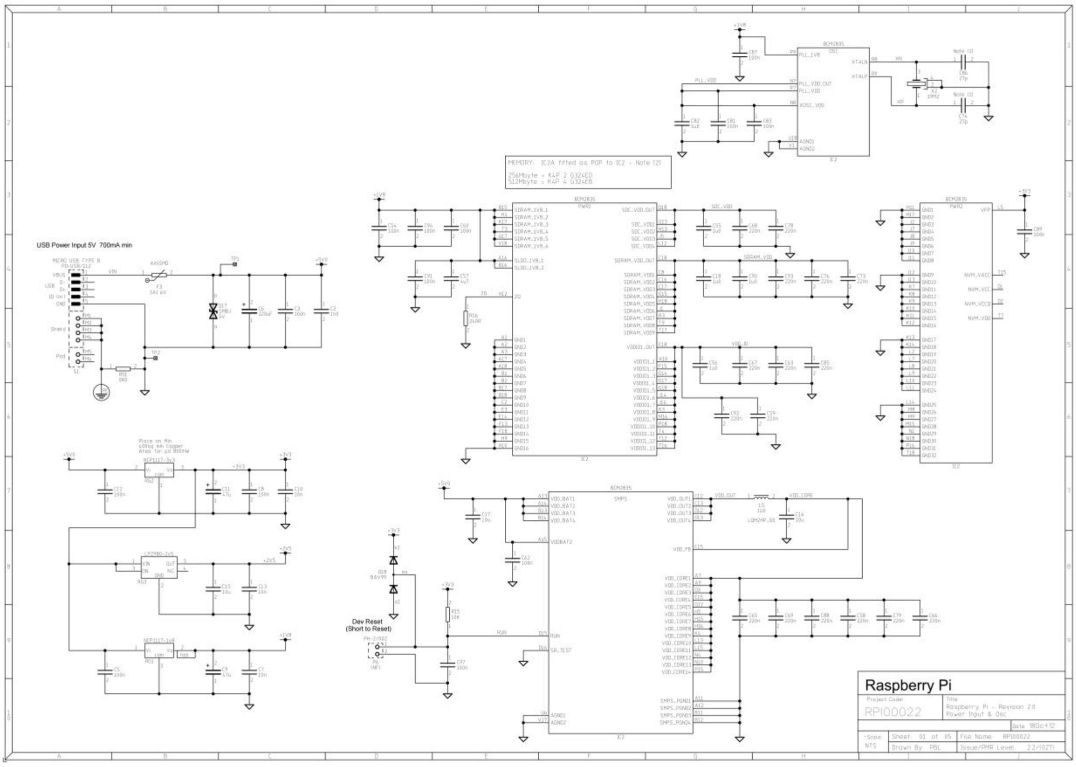
[8] Mohan, S., & Rangaswamy, T. (2019). Ultrasonic Sensor Based Obstacle Detection and Avoidance System for Autonomous Robots. International Journal of Engineering and Advanced Technology, 8(3), 1904-1908.

[9] T. Qin, P. Li and S. Shen, "VINS-Mono: A Robust and Versatile Monocular Visual-Inertial State Estimator," in IEEE Transactions on Robotics, vol. 34, no. 4, pp. 1004-1020, Aug. 2018, doi: 10.1109/TRO.2018.2853729.

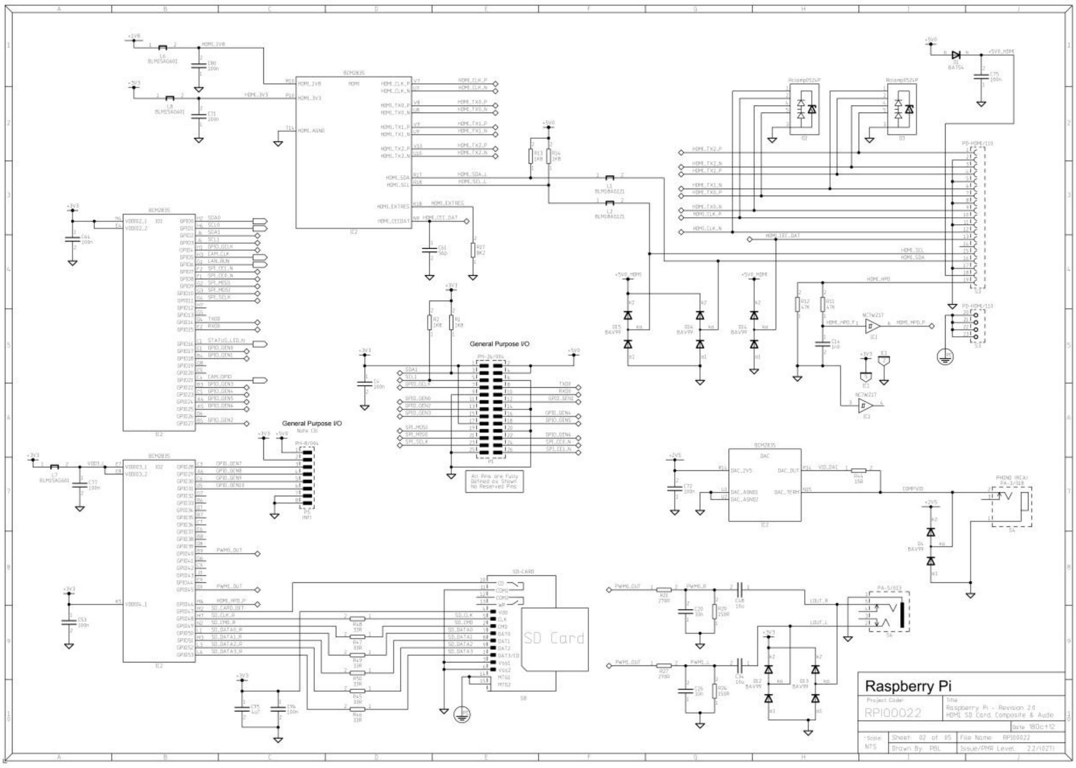
[10] J. Engel, V. Koltun and D. Cremers, "Direct Sparse Odometry," in IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 40, no. 3, pp. 611-625, 1 March 2018, doi: 10.1109/TPAMI.2017.2658577.

[11] T. Schöps, T. Sattler and M. Pollefeys, "BAD SLAM: Bundle Adjusted Direct RGB-D SLAM," 2019 IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), Long Beach, CA, USA, 2019, pp. 134-144, doi: 10.1109/CVPR.2019.00022.

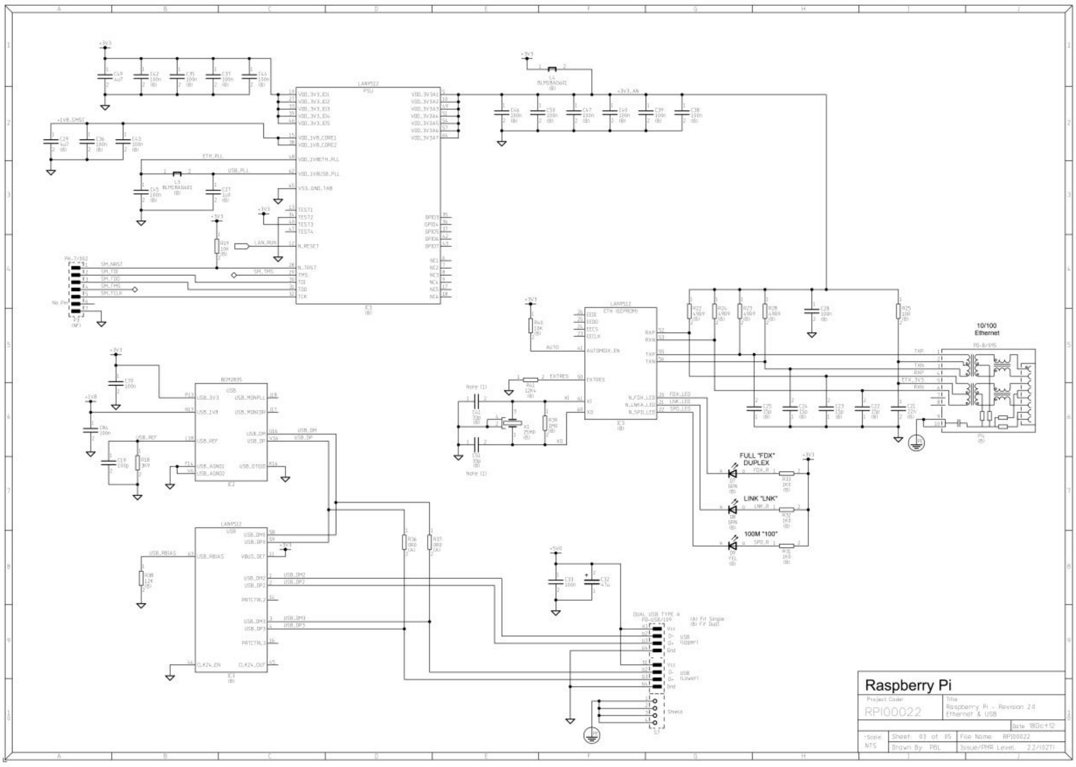
Appendix A Engineering Drawings



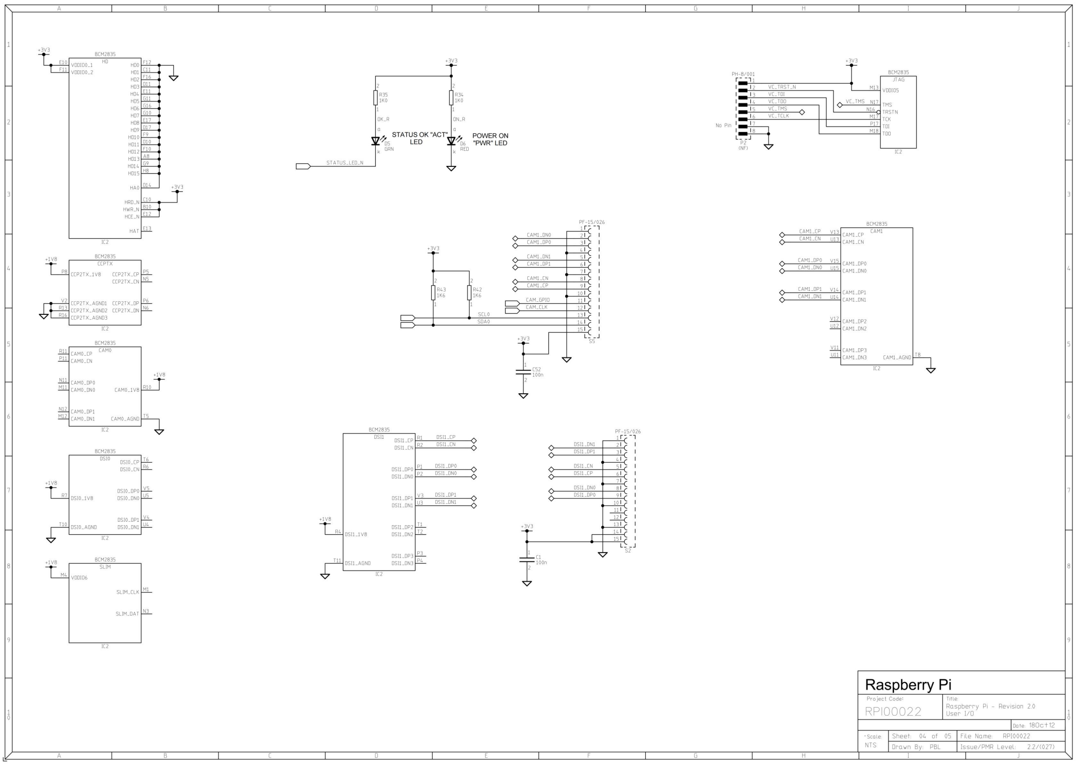
Raspberry PI pin diagram(a)



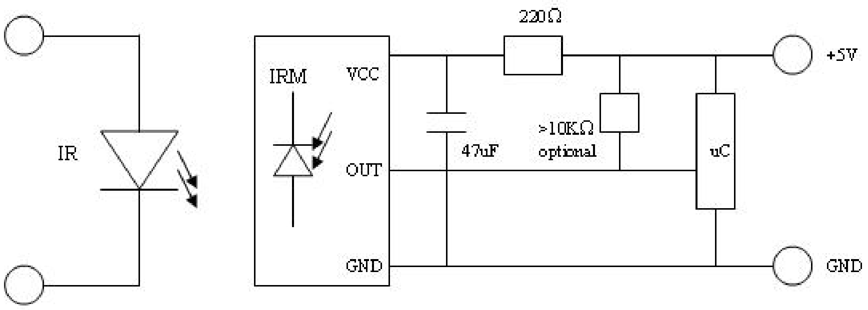
Raspberry PI pin diagram(b)



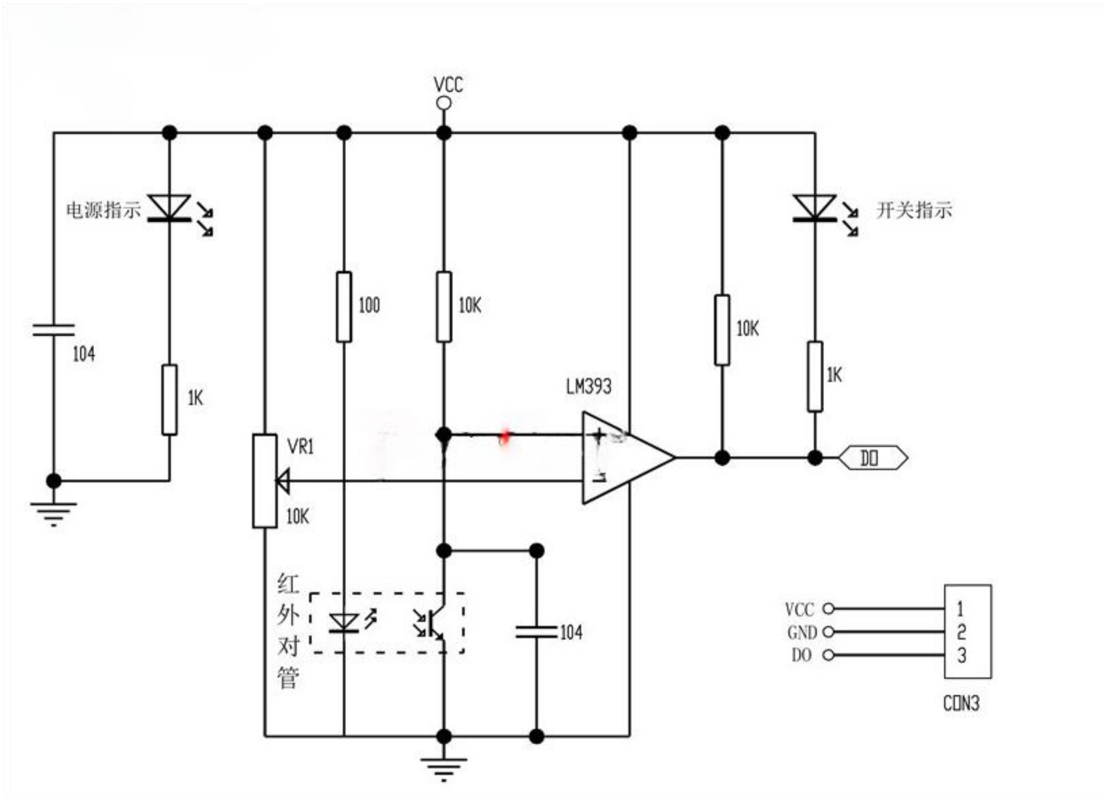
Raspberry PI pin diagram(c)



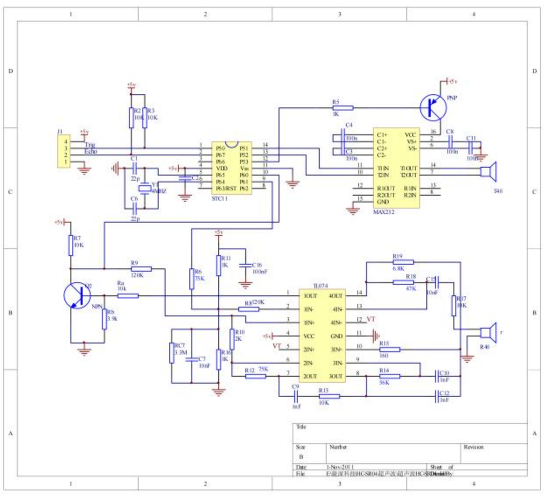
Raspberry PI pin diagram(d)



Remote controller schematic



Infrared obstacle avoidance schematic diagram



Schematic diagram of ultrasonic sensor

Item	Unit	Min	Typical	Max	Comments
Distance Range	Meter(m)	TBD	0.15-12	TBD	White objects
Angular Range	Degree	n/a	0-360	n/a	
Scan Field Flatness	Degree	-1.5		1.5	
Distance Resolution	mm	n/a	<0.5 <1% of the distance	n/a	<1.5 meters All distance range*
Angular Resolution	Degree	n/a	≤1	n/a	5.5Hz scan rate
Sample Duration	Millisecond(ms)	n/a	0.125	n/a	
Sample Frequency	Hz	n/a	≥8000	8010	
Scan Rate	Hz	1	5.5	10	Typical value is measured when RPLIDAR A1 takes 360 samples per scan

RPLIDAR Performance

Appendix B Components' name and price list

	Component	Price
1	Robot	Provided by Supervisor
2	Infrared sensors	Provided by Supervisor
3	Ultrasonic sensors	Provided by Supervisor
4	Power bank	￥78
5	Acrylic board	￥24
6	RP LIDAR A1	Borrowed from lab
7	Camera	Borrowed from lab

Appendix C Individual Contribution Form

Everyone on our team helped each other and worked through the project together, including the report, poster, video and the physical prototype, so our work overlapped. In the following contributions, we list only the most important ones made by each person.

Student Name/ID	Contribution Percentage	Brief description of individual contribution
Yilin Cao	20%	LIDAR SLAM, poster and report.
Jifeng Li	20%	LIDAR SLAM and camera use.
Zhiyang Zhao	20%	Video, robot control.
Yilin Yang	20%	Infrared and Ultrasonic sensor, robot control.
Yihan Lu	20%	Basic movement, user study and report.