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Design Review #3

Advanced Development on State-of-art Robots

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1 Introduction

1.1 Background

Some daily scenarios, such as tour guide or caring for the elderly, lack a complete software solution under robot platforms. They are now done by human and has many problems. As human resource gets more and more expensive, human solution for some specific scenario is no longer available. Also, human solution for some scenario is not as perfect as a robot solution, since human will not be able to focus and 'operate' for a long time. Therefore, a robotic solution for such scenario is in need.

1.2 About our project

Our project aims at developing robot applications on open source robot platforms such as NAO or Cruzr to meet the requirements from a specific scenario, and providing a complete traceable technical document. The scenario it faces can be decided by our own. We decide to develop a robot aiming at taking group photos. Now, when we take a group photo, we need to find someone to take the photo for us, which is not always possible. We can also take the photo ourselves, but whether a photo is good depends much on the person taking the photo, and it is not possible when there are many to be photographed. Our project aims at solving this kind of problem and developing a service robot that can take a group photo in a professional manner and adjust itself according to customer's comments.

1.3 Customer needs

Our sponsor requires us to develop a software solution for a specific scenario under open source robot platforms such as NAO or Cruzr. We can decide the scenario and which open source robot platform we use.

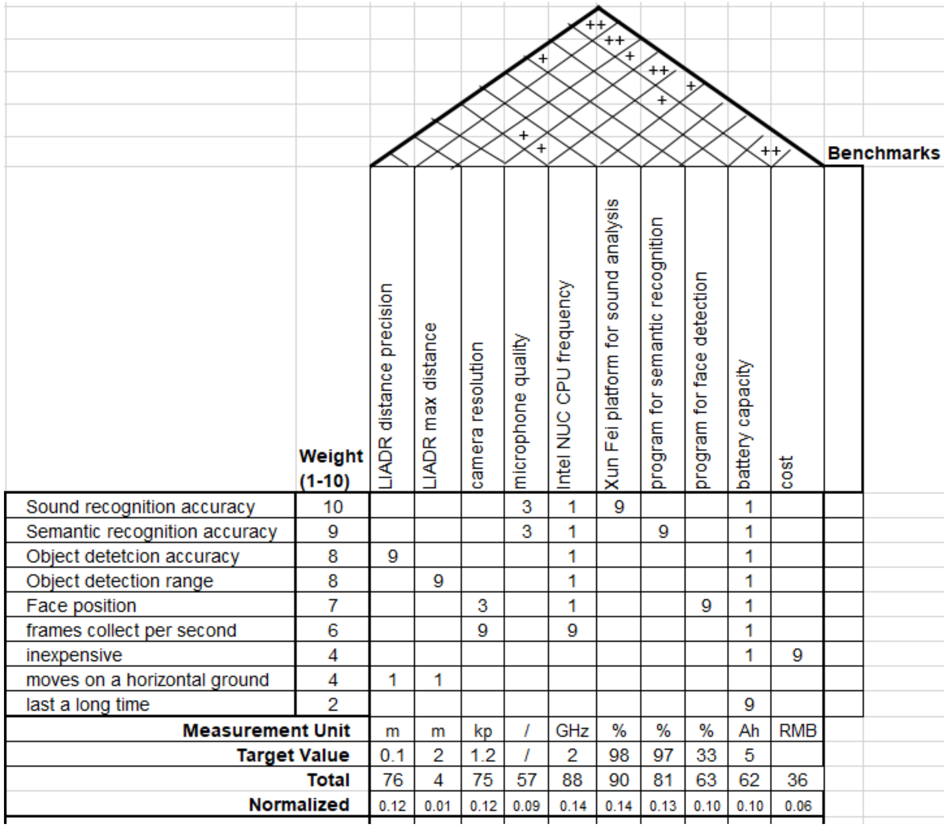
According to the scenario we choose, several requirements are generated. They are listed below.

1. The robot should be able to adjust itself to the group to be photographed to ensure that all people being photographed is in the figure and they are close to the center of the picture.
2. The robot should always let the customer see what the current figure looks like.
3. The robot should be able to be controlled by sound to move its position and adjust its camera.
4. The robot should avoid collision when moving.

We think that those requirements will include all real life needs of customers under such scenario. To meet these requirements, some engineering specifications are generated.

2 Engineering Specifications

The engineering specifications are shown in the QFD chart in Figure 1.



	Weight (1-10)	LIADR distance precision	LIADR max distance	camera resolution	microphone quality	Intel NUC CPU frequency	Xun Fei platform for sound analysis	program for semantic recognition	program for face detection	battery capacity	cost	Benchmarks
Sound recognition accuracy	10				3	1	9			1		
Semantic recognition accuracy	9				3	1		9		1		
Object detetcion accuracy	8	9				1				1		
Object detection range	8		9			1				1		
Face position	7			3		1			9	1		
frames collect per second	6			9		9				1		
inexpensive	4									1	9	
moves on a horizontal ground	4	1	1									
last a long time	2									9		
Measurement Unit		m	m	kp	/	GHz	%	%	%	Ah	RMB	
Target Value		0.1	2	1.2	/	2	98	97	33	5		
Total		76	4	75	57	88	90	81	63	62	36	
Normalized		0.12	0.01	0.12	0.09	0.14	0.14	0.13	0.10	0.10	0.06	

Figure 1: QFD chart

The sponsor does not have any requirement on our project, as long as we use the open source platform he provides. We figured out the engineering specifications on our own according to the scenario we chose.

Since the users should be able to control the robot remotely with voice, we want the sound recognition accuracy and semantic recognition accuracy to be high. Therefore, the following to requirements have a high weight and high specification.

1. Semantic recognition accuracy ≥97 %
2. Sound recognition accuracy ≥98 %

Collision is very dangerous in real life usage. Therefore, collision avoidance is the next important thing we need to ensure, which is realized by a LiDAR. The accuracy and maximum range of the LiDAR is required as follows.

1. Accuracy ≥0.1
2. Maximum distance ≥2m

We want the final picture taken to be good and professional, and therefore we want all faces are in the picture and all people are close to the center of the picture. Also, we want the picture to be refreshed quickly, which depends on the CPU power and camera resolution. The given specification are as follows.

1. CPU frequency ≥2.0GHz

2. Camera resolution ≥1200w pixels
3. Face position within center 1/3 of picture
4. Frames collected per second ≥30

3 Concept Generation

The sub-systems of our project is generated with brainstorms according to the requirements of our selected scenario. To satisfy the needs, four sub-systems are generated. The morphological chart is shown in Figure 2.

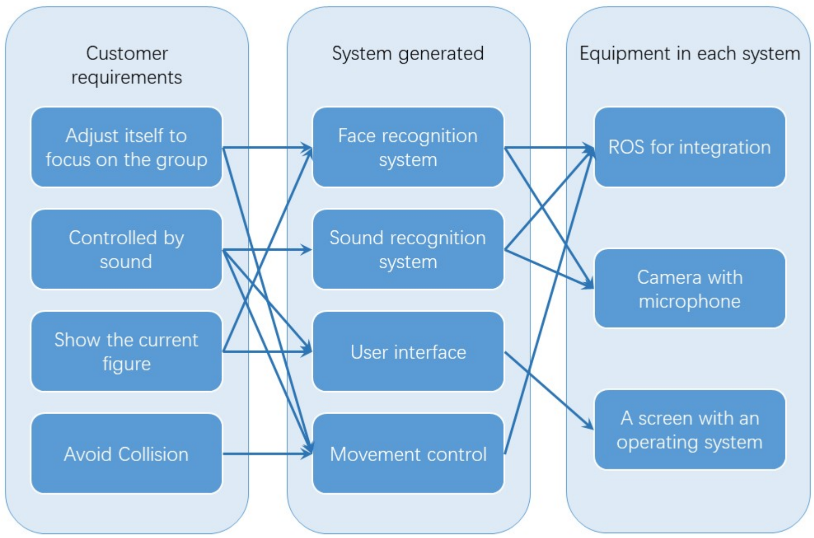


Figure 2: Morphological chart

The detailed descriptions are:

1. In order to let the robot move, a movement control system is needed. Also, the movement control system will have to ensure that the robot will not collide in any object or human during moving.
2. In order to let the robot adjust itself according to the group being photographed, the robot has to detect all the faces within the picture and locate them close to the center of the picture. This will require a face detection system. According to the faces detected, the robot will communicate with the movement control to let the robot move left, right, forward or backward and move the camera upwards or downwards to make all faces close to the center of the figure.
3. To let the customer control the robot with sound, the robot has to recognize the sound taken by the microphone. A sound recognition system is needed to recognize the voice instructions from the customer and translate them to commands that can be used by the movement control system.
4. A user interface should be developed to show the current figure to the customer. Also, any instruction came from the customer such as send the picture to phone can be showed in the user interface.

4 Concept Selection Process

4.1 Chassis Control System

The chassis consists of two DC motors with high-precision encoders and two corresponding wheels, which are provided by our sponsor. The main function of the chassis control system is to detect obstacles and avoid collisions, while the function of moving has already been built in ROS. To implement this function, several engineering specifications are found as:

1. The measurement of distance should be precise as 0.01 m.
2. The hardware should be able to measure surroundings at any direction.
3. The detection range should be greater than 0.5 m, which is the safe range we define.

With these specifications, we find three commonly-used device as:

1. LiDAR
2. Depth Camera
3. Ultrasonic sensor

The corresponding scoring matrix is shown as in Fig 3.

Design criterion	Weight factor	Unit	LiDAR			Depth Camera			Ultrasonic Sensor		
			Value	Score	Rating	Value	Score	Rating	Value	Score	Rating
Detection range	0.30	m	4	8	2.4	1.5	4	1.2	5	9	2.7
Distance precision	0.30	mm	0.1	9	2.7	0.5	6	1.8	1.5	4	1.2
Cost	0.05	RMB	500	8	0.4	1200	4	0.2	650	6	0.3
Response time	0.20	ms	0.2	10	2	16.7	6	1.2	20	4	0.8
Durability	0.15	/	High	8	1.2	High	8	1.2	Fair	6	0.9
					8.7			6.4			5.9

Figure 3: Chassis control system scoring matrix

We can see from Fig 3 that LiDAR gets the highest scores compared to the other two. For all design criterion, LiDAR shows itself as the best solution to our requirements.

Hence, LiDAR is chosen to be implemented with motors and wheels to handle detection.

4.2 Sound Recognition System

Sound Recognition System is used to manually adjust the position of robot and camera to make the photo better. So, we hope the voice recognition system can distinguish our order quickly and accurately. To implement this function, several engineering specifications are found as:

1. This system should support speech wake-up function. Also, this function should be naturally.
2. This system should have a high accuracy of speech recognition.
3. This system should have high semantic resolution accuracy.
4. This system shouldn't cost too much.
5. This system should support Linux operation system.

With these specifications, we find three commonly-used open platform as:

1. Xun Fei Open Platform
2. Baidu Open Platform
3. Tencent Cloud

The corresponding scoring matrix is shown as in Fig 4.

Design criterion	Weight factor	Unit	Xun Fei			Baidu			Tencent		
			Value	Score	Rating	Value	Score	Rating	Value	Score	Rating
Speech Wake-up Naturality	0.30	%	98	9	2.7	93	8	2.4	0	0	0
Speech Recognition Accuracy	0.30	%	98	9	2.7	97	8	2.4	94	6	1.8
Semantic Resolution Accuracy	0.30	%	97.4	9	2.7	96	8	2.4	92	5	1.5
Cost	0.05	RMB	200	6	0.3	0	10	0.5	0	10	0.5
Support Linux	0.05	/	Yes	10	0.5	Yes	10	0.5	Low	6	0.9
					8.9			8.2			4.7

Figure 4: Sound recognition system scoring matrix

We can see from Fig 4 that Xun Fei Open Platform gets the highest scores compared to the other two. For all design criterion, Xun Fei shows itself as the best solution to our requirements.

Hence, Xun Fei Open Platform is chosen.

4.3 User Interface

The concept selection process of the subsystem of user interface mainly concerns on the following three aspect:

1. The CPU capability of the device. Our device also serves as the server for our sound recognition algorithm and face detection algorithm. These process can be a burden for the device. We require a device with CPU at least capable of containing all the processes at the same time.

2. The system running on the device. Since the device serves as the terminal for robot-base-control, camera, microphone, speaker and LiDAR. We need a system on which python, ROS and all these hardware can all work well.

3. The User Interface application workload. At last we need to design a user interface application running on the device interacting with the user interface. Due to the limited time provided for the project, we need a system easy for development ensuring the best user experience.

Other affecting facts include the performance of Bluetooth which we use to send our photo to our user. A solid touchscreen where users interact with the system. We also should take the cost into consideration.

With all these facts and requirements in head, we have come up with the following top five concepts to select from, they are all named by the device name:

1. Intel NUC with touchscreen (Linux)
2. Microsoft Surface (Windows 10)
3. Android pad (Android)
4. Apple IPad (IOS)
5. Raspberry Pi with touchscreen (Linux raspbian)

To compare between the five concepts, we make the following scoring matrix.

Design criterion	Weight factor	UNIT	Intel NUC with Touchscreen			Android Pad			iPad		
			Value	Score	Rating	Value	Score	Rating	Value	Score	Rating
Hardware and Ros Compatibility	0.30	/	mature	10	3	mature	10	3	not mature	0	0
UI workload	0.20	week	4	10	2	8	5	1	8	5	1
CPU capability	0.20	GHz	2.4	8	1.6	1.8	6	1.2	2.49	8	1.6
Bluetooth performance	0.10	/	Solid	10	1	Solid	10	1	Solid	10	1
Touchscreen performance	0.10	/	Solid	10	1	Solid	10	1	Solid	10	1
Cost	0.10	RMB	4000	8	0.8	3500	9	0.9	4000	8	0.8
Total					9.4			8.1			5.4

Figure 5: UI scoring matrix (part1)

Design criterion	Weight factor	UNIT	Raspberry Pi with Touchscreen			Microsoft Surface		
			Value	Score	Rating	Value	Score	Rating
Hardware and Ros Compatibility	0.30	/	not mature	0	0	mature	10	3
UI workload	0.20	week	4	10	2	8	5	1
CPU capability	0.20	GHz	1.5	5	1	2.6	9	1.8
Bluetooth performance	0.10	/	Solid	10	1	Solid	10	1
Touchscreen performance	0.10	/	Solid	10	1	Solid	10	1
Cost	0.10	RMB	1000	10	1	6400	5	0.5
Total					6			8.3

Figure 6: UI scoring matrix (part2)

From the matrix we can find that Intel NUC with touchscreen and Linux system get the highest rating. From the weight factor of different design criterion, we can find that the compatibility is the deciding factor in this concept selection. Concepts with immature compatibility are eliminated even if they may have the advantages in other category. Besides, our selected concept, which is the Intel NUC mini computer, has lighter UI workload and reasonable CPU capability. These advantages help it defeat the other two candidate.

Besides, the Bluetooth performance and the touchscreen performance are also important for function realization. However, since all of the top five concepts to choose from have solid performance. Their weight is also reduce to 10 percent.

As a conclusion, we choose NUC mini computer from Intel as the device running UI.

5 Selected Concept Description

5.1 Chassis Control System

5.1.1 Engineering Design Analysis

As mentioned in Section 4.1, the engineering specifications for the chassis control system are detection precision, scanning angle and maximal detection distance. LiDAR fits all these specifications as it scans the surrounding for 360 degrees with the precision of 0.1 mm and maximal distance of 4 m. Since the robot kit is provided by our sponsor, which has ROS built in within, we choose to use simultaneous localization and mapping (SLAM). This is a common package in ROS regarding robots' localization and navigation. Combined with other packages in ROS, we can write our own program to control the movement of our robot.

LiDAR is then installed on our robot in the middle layer. The chassis of our robot is provided by our sponsor, so are LiDAR and the depth camera. Thus, we can only choose one of them. LiDAR is chosen due to the highest score of the socring matrix shown in Fig 3.

5.1.2 Design Description

The software part is described by the flow chart in Fig 7. Since the hardware, such as LiDAR and motors, are provided by our sponsor, which they purchased from Intel, a detailed layout drawing with dimensions cannot be made.

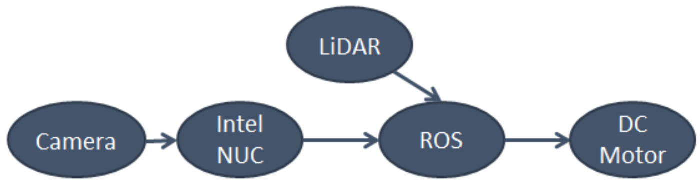


Figure 7: Chassis control system flow chart.

The algorithm behind our robot is first to gather image and data from the camera, which has a microphone. Then the host, Intel NUC, can calculate the best position for a group photo, if there are no voice commands; otherwise, Intel NUC can separate the key word from the voice and convert it to the command. In either case, Intel NUC sends the moving commands to ROS, which is connected to LiDAR. While ROS controls the motors according to the commands, it monitors the surrounds. If a person, or something, is detected by LiDAR to be too close, ROS will immediately stop the robot until the path is clear.

5.2 Sound Recognition System

5.2.1 Engineering Design Analysis

As we mentioned before, the sound recognition system is used to transfer our speech to the final order. Here, Speech Wake-up Naturality, Speech Recognition Accuracy and Semantic Resolution Accuracy are all important to the effect of our project. The naturality of speech wake-up decideds whether we can wake the system up quickly at the time we want. Besides, it also ensures that the system won't waste resources when we don't need it. The high accuracy of speech recognition provides us with the assurance that he can accurately identify our instructions. Also, since sometimes we need to accept instructions in Chinese, we need our system to support semantic resolution. These three parameters are the most important for the performance of the sound recognition system. What's more, the support of Linux and the cost of it are also crucial. Using scoring matrix, Xun Fei is finally choosed. It has an extremely high accuracy rate of 98, 98 and 97.4 percents in these three aspects. It also support the Linux system and has a low cost.

5.2.2 Design Description

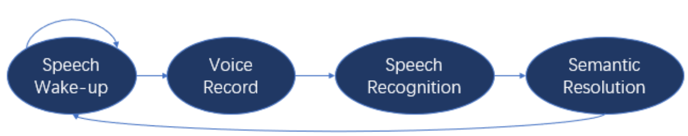


Figure 8: Sound recognition system flow chart.

As shown in flow chat in Fig 8. The sound recognition system will keep detecting for key words to wake-up. Once it detects the key words we set, it will start to record the voice using the microphone and save it as a wav file. After that, the wav file will be uploaded to the open platform and be transferred to a sentence there. Then, we will use word segmentation technology to extract the instructions. Then the system will sleep ant wait for the next wake-up instruction.

5.3 User Interface

5.3.1 Engineering Design Analysis

The engineering fundamentals support this concept is the ability to check the compatibility between hardware and the terminal, the communication between different programming environment as well as a concept of MVC frame for the UI application. The compatibility between hardware determine whether the camera, microphone, LiDAR, base-element and speaker can function as they are expected on our robot. The communication between languages allow data and signals to be received and emitted in the terminal. The MVC frame concept enables us to establish a frame on which we build our UI.

The determination of specific parameter are mainly based on a positive-negative mechanism. Most of the compatibility test would give out a result of yes or no which directly tells us whether the device meet the requirements. Three of our parameters on determined by the standard level of technology. The pixar, the time for Bluetooth to send the photo and the FPS are of the average level of the products we can acquire from the market. Also the parameter of CPU is determined the calculation amount of the algorithm.

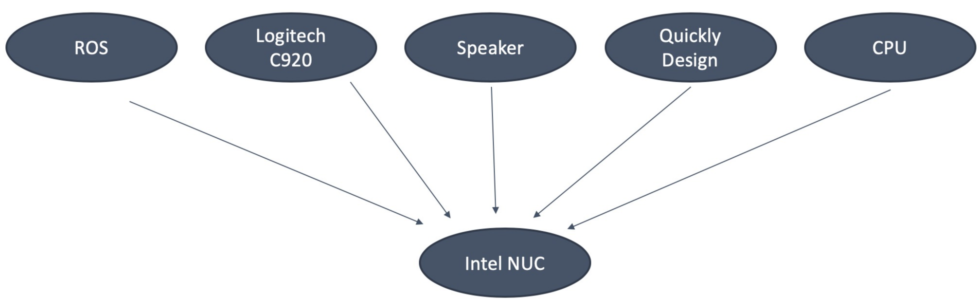


Figure 9: Rationale Behind Decision of UI

The rationale behind the decision can be split into several parts.

1. ROS. ROS is an operation platform dedicated to robot development based on the Linux system. With the platform, huge amount of open source codes and scripts can be found for base-control, camera detection and communications between different parts. It also have it's unique file system with Linux to enable the synchronization of multi-process. These property of ROS leads us to a Linux operation system.

2. Logitech C920. USB-camera is now widely supported on Linux system and can be detected by the node "usb-cam" embedded in ROS. Also there are drivers out there for the PID and VID of USB camera product from logitech. Due to it's high photo quality, reasonable size and weight, we resemble it with our Linux terminal.

3. Quickly Design. Quickly Design is a tool enabling us to quickly setup a UI framework on which we can write our UI program. The tool provides graphic interface for UI design and established python files to link functions with buttons. The tool lead us to our Linux system because it can significantly lower the workload of UI.

5.3.2 Design Description

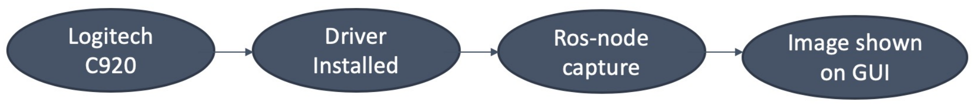


Figure 10: UI Flow chat 1

After sufficient research is done to prove that Logitech C920 can work well with ROS and Linux. We purchase the camera from online website. Than we install the open source drive written for this camera model on Linux. Then we run the ROS and the command "Roslaunch usb-cam" in the shell. In the last step we capture the stream from the camera from a GUI tool named rqt-image-view. The hardware is successfully installed into the system

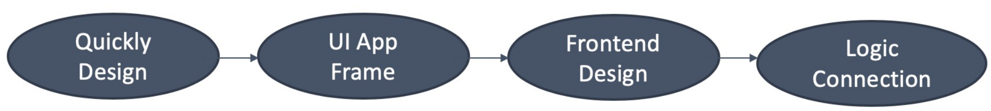


Figure 11: UI Flow chat 2

First we need to install the tool named Quickly. With this tool installed, we can use it to create an App project on ubuntu with basic MVC frame already written inside. Than we use a UI design tool called "glade" to design the graphic part of the UI. In the end, we connect different actions and functions through the code in python files the project has already built up. The UI is now functioning as we expected.

6 Implementation and Validation Plan

6.1 Implementation plan

Our sponsor WECAN company provided Ros Kit robot to us, and we integrated a lead screw with Logitech C920 Camera onto the robot. The prototype is shown in Figure 12. The hardware component needs a corresponding software implementation, which is listed on the right.

All software implementation uses Python. The face recognition system uses opencv library to detect the position of faces in the photo. The sound recognition system uses Xunfei online platform to get JSON string from audio input. The chassis movement control is implemented on ROS platform. We use the navigation library to get the map around the robot, formed using LiDAR, and use the map to avoid collision with obstacles. The user interface uses glade to integrate all the functions inside a graphical tool.

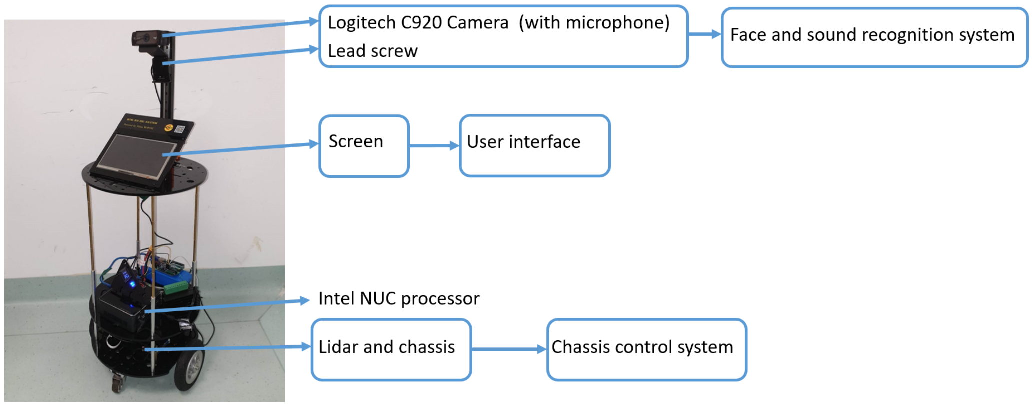


Figure 12: Photograph robot prototype

6.2 Budget

The parts we used in this project are listed in table 1. The total cost is within the expected budget.

Item	Price (RMB)	Source
Ros Kit	-	Provided by sponsor
Logitech C920	499	https://detail.tmall.com/item.htm?id=37176770174
Metal Connecting rod	60	https://item.taobao.com/item.htm?id=565472938246
Arduino Uno Board	240	https://detail.tmall.com/item.htm?id=592121292238
Electric Motor with encoders	90	https://item.taobao.com/item.htm?id=597532302078
Electric Lead Crew	60	https://detail.tmall.com/item.htm?id=553656246409
Wireless Display Adaptor	319	https://item.taobao.com/item.htm?id=561732610255
Voice recognition platform	200	https://www.iflyrec.com/
Total	**1468**	

Table 1: Budget

6.3 Validation Plan

To ensure the customer requirements are met with our prototype, we will test our robot in the following scenario. The robot first moves according to the voice instructions. When it detects an object and stops. a ruler is used to measure the distance between the edge of the robot and the object. The accuracy of sound recognition and semantic recognition can be assured by the platform we used. After we take a picture, the place of the face in center of a group relative to the whole picture can be measured using a ruler. Some other specifications can also be read from the program.

The expected validation results are:

1. CPU frequency $\geq$2.6GHz
2. Speech recognition accuracy $\geq$98
3. Semantic recognition accuracy $\geq$98
4. frames collected per second $\geq$30
5. Object detection range $\geq$2m

6. Distance measured precision ≥0.1m
7. Center face place: in middle 1/3 of the photo

Up till now, we have met the requirements 1-6. We are still working on the face detection and auto-adjustment to achieve the center face place requirement. This result ensures all the customer requirements and engineering specifications listed in section 2 are met.

7 Project Timeline

The gantt chart is attached in Figure 13 and 14. The labels behind each task are the assigned teammates' first character of his/her first name. We finished voice recognition, motion control, collision avoidance on time. We also finished user interface implementation ahead of time. The major remaining task for us to do before the EXPO is the automatically robot position adjustment, based on face detection. We are currently on a good track in progress. We will also do more test, and refine for our prototype and user interface in the last few days.

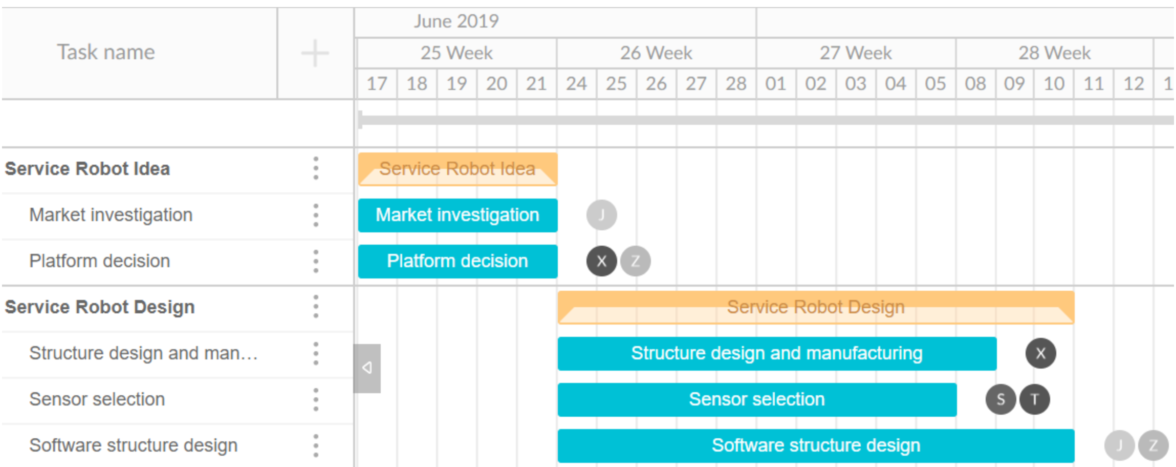


Figure 13: Gantt Chart (part 1)

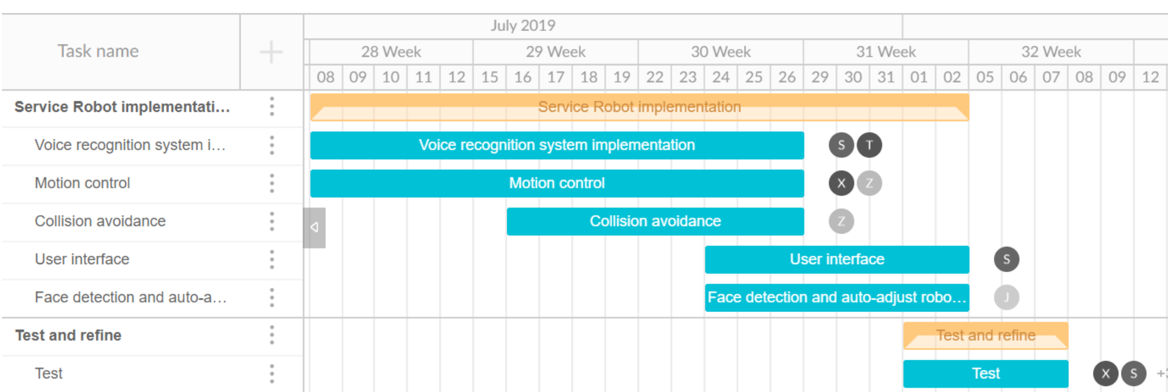


Figure 14: Gantt Chart (part 2)

8 Analysis of Potential Problems

The are several potential problems may occur in the next few days development, and during the EXPO demonstration. We also have corresponding plans to concur the problems.

1. The motion controller system need to be tuned for different moving environment.

   The motion control system is sensitive to the friction of the ground. To ensure the robot is moving appropriately with a given command, we will test and tune it at our EXPO place.

2. The sound recognition system may have higher delay if the wifi gets crowded during EXPO.

   If the sound system cannot work appropriately in real time during the EXPO, the user can also adjust the robot pose using the keyboard as a backup plan.

3. The data transmission between camera to user interface may be delayed.

   We will use Microsoft wireless display adapter, to enhance the graph transmission speed. This will enhance the users' experience when they using voice to adjust robot pose in real time.

9 Conclusions

To design, build and implement a indoor photograph robot, we divided our tasks into four parts: sound recognition, face detection, motion control and graphical user interface. With these four function, our robot can move around and adjust its position automatically according to where the faces are in the photo. Also, people can further adjust its position using voice command, and it will avoid collisions with people passing-by. After taking a photo, people can get the image through our user interface via Bluetooth.

After investigating and compare several platforms fro implementation, we make the following decisions:

1. Motion control system is implemented by Robot operating system (ROS) platform. The collision avoidance uses LiDAR to measure the distance.

2. Sound recognition system is implemented by XunFei online platform.

3. User interface is implemented on Intel NUC with Touchscreen using glade.

All of the implementations are using Python. After integrating all the parts onto the robot and finish the implementation, the validation result shows these three systems satisfies our engineering specification.

The face detection system still remains to be implemented through openCV, and we are currently working on this part. It is expected to be functioning and satisfying our specification during the final EXPO.

10 References

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11 Bios

I am Ziyou Wu. I'm a senior undergraduate student major in Mechanical Engineering in Shanghai Jiaotong University, and major in Data Science, minor in Mathematics in University of Michigan. I did research projects in biologically inspired dynamical systems lab in UM. My research interest lies in multi-legged robot locomotion and its control theory. I will continue my PhD journey in UM robotics next semester. My ultimate career goal is to become a professor, bringing novel ideas into academia and cultivating next generation engineers and scientists.

I am Xinyu Lin, a senior undergraduate student majoring in Mechanical Engineering at Shanghai Jiaotong University, and also a master student of Vehicle Engineering at KTH Royal Institute of Technology. I am interested in autonomous driving, which is why I have applied vehicle engineering for my master degree. For the coming fall, I am going to finish my courses at KTH and start doing my master thesis.

I am Tailun Liu, an undergraduate student majoring in Mechanical Engineering at Shanghai Jiao Tong University. I will go to University of Southern California to further study in the major and get a Master degree. I am interested in System Control, and I am planning to choose this as my field of interest. Whether I will do a thesis remains undecided, but I have already found some interesting topics and professors at USC. After I graduate from USC, I plan to enter the industry, doing work related to robot design and automatic design. Doing PhD is also an option, though. I may want to further my study in the field of control and automatics, but I do believe under any condition, an experience in the industry will help a lot in my study and my understanding towards my major. I do not intend to pursue an academic career, and I want to step into the industry after I end my study. Being a mechanical engineer is always my ambition since my childhood. I do not deny the influence from parents, since they both are engineers as well, but I feel mechanical engineering is what I want to lay my emphasis on, and what deserves my life to focus on. I believe I would be happy in such kind of a job.

I'm Sidong Wang, a senior student majoring in Electrical and Computer Engineering at Shanghai Jiao Tong University. I'm heading to USC to pursue my master degree in Applied Data Science after my graduation this summer. There I'm going to focus on machine learning, database application and algorithm development. There would be of great possibility of me to enter the employment market after my graduation from my master degree. I would be interested in the field of industrialization of big data analysis and characteristic recognition when I'm applying for potential job position and I'm also interested in developing interaction UI for different kind of application.

I'm Jiazhen Ji, a senior student majoring in Electrical and Computer Engineering at Shanghai Jiao Tong University. I'm interested in autonomous driving system. I wanna to be an autonomous driving system engineer in future. That's one of my main reason for choosing this topic as my capstone project. After graduating from Shanghai Jiao Tong University, I plan to go to New York University for further research on autonomous driving system and computer vision.