ECE 445

SENIOR DESIGN LABORATORY

DESIGN DOCUMENT

Robot Vacuum

Team #9

TIANYU ZHANG
(tianyu7@illinois.edu)
LONG CHANG
(longc2@illinois.edu)
ZHEYI HANG
(zheyih2@illinois.edu)
KAILONG JIN
(kailong3@illinois.edu)

TA: Tielong Cai
Mentor: Meng Zhang

March 24, 2023

Abstract

Household robot vacuums have provided human convenience by automating floor cleaning work. However, the functionality of robot vacuum is not perfect and problems can happen in its daily usage. In a big house with multiple floors, it will be sad to see the robot falling from high places. Sometimes, the robot may be confused by the small obstacles on the floor, causing it to get stuck or have an inefficient path to clean the room. So we plan to propose a robot vacuum that can avoid such problems. By adding anti-falling wheels and a suspension system, our robot can prevent falling from high platforms and can pass through short objects on the floor. We will also improve its path-finding algorithm by taking its ability to pass obstacles into consideration. Furthermore, we will allow the robot to interact with a lift to make it possible for multi-floor cleaning.

Contents

1 Introduction

1.1 Problem

As technology advances, robot vacuums have become increasingly popular in recent years. At the same time, they have been gradually upgraded from basic models with a single sweeping function to more intelligent devices with a certain level of intelligence, including identifying room types, video monitoring pet activities, and even family calls. Despite these advancements, however, from our daily experience in the use of robot vacuums, there still exist many problems that need to be addressed. One issue is that the robot vacuum may fall from a high plane and break. The other is the potential to get stuck when passing through uneven surfaces. Additionally, it cannot finish the cleaning work on several different floors without manually moving it to the next floor over and over again. Finally, the path-finding algorithm can still be improved to optimize performance. To further reduce the work that workers need to do personally and enhance the reliability of the robot vacuum, the four problems above have the urgency to be solved.

1.2 Solution

We propose an advanced version of the robot vacuum that can tackle the problems mentioned in section 1.1. Specifically, we design four separate subsystems and then integrate them into the existing robot vacuum. Firstly, the anti-fall steering system will automatically steer the robot when it approaches the edge of the stairs by adding a mechanical structure to the bottom of the vacuum. Secondly, the suspension structure will be improved to give the robot vacuum better adaptation to a variety of complex and uneven working terrain. To be specific, the chassis of the vacuum will automatically get raised when the infrared sensors detect that the vacuum is approaching some low obstacles. This second subsystem is called the low obstacle passing subsystem. Thirdly, the elevator interaction subsystem allows the robot vacuum to call the elevator to reach the floor it is now working on and then send itself to the next floor through signal transmission between the two. In this way, it can perform sweeping work across several different floors simply by interacting with the elevator. Lastly, we will optimize the 2D/3D vision of today's robot vacuum and optimize the path-finding algorithm to further improve its efficiency and power. These constitute the fourth subsystem called the effective path-finding subsystem. The integration of these four subsystems will enhance the capabilities of the robot vacuum, making it more reliable and efficient, and reducing the workload required of workers.

1.3 High-Level Requirements List

- The robot vacuum should be able to pass over thresholds or obstacles whose heights are less than 2cm smoothly without getting stuck.
- The algorithm the robot vacuum adopts should be able to deal with situations where low obstacles exist, and the efficiency should be improved by at least 5% compared

with the existing ones.

- The signal transmission between the robot vacuum and the elevator should be strong enough to ensure that every time when finishing the clean work of one floor, the vacuum can call for the elevator to send itself to the next floor to continue its work.

1.4 Visual Aid

Figure 1 below illustrates how our robot vacuum is expected to do.

- For Figure 1 upper-right part, our robot vacuum turns around when it is about to fall from the platform.
- For Figure 1 upper-left part, our robot vacuum can smoothly cross over the threshold without getting stuck.
- For Figure 1 lower-left part, our robot vacuum has interactions with an elevator to do multi-floor cleaning work.
- For Figure 1 lower-right part, our robot vacuum can generate a path to clean the entire room efficiently.

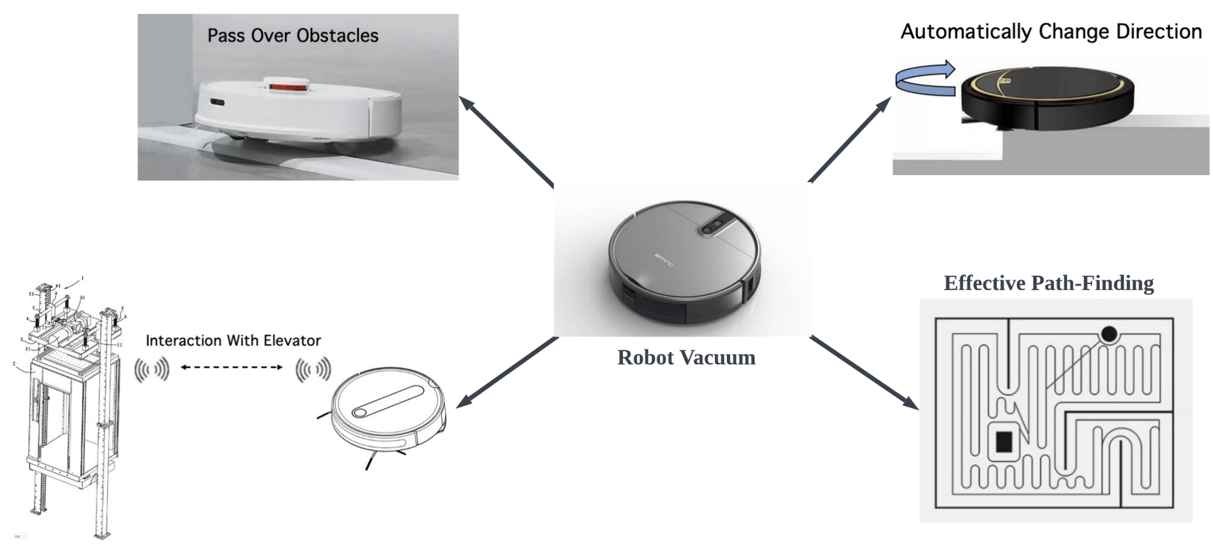

Figure 1: Visual Aid

2 Design

2.1 Block Diagram

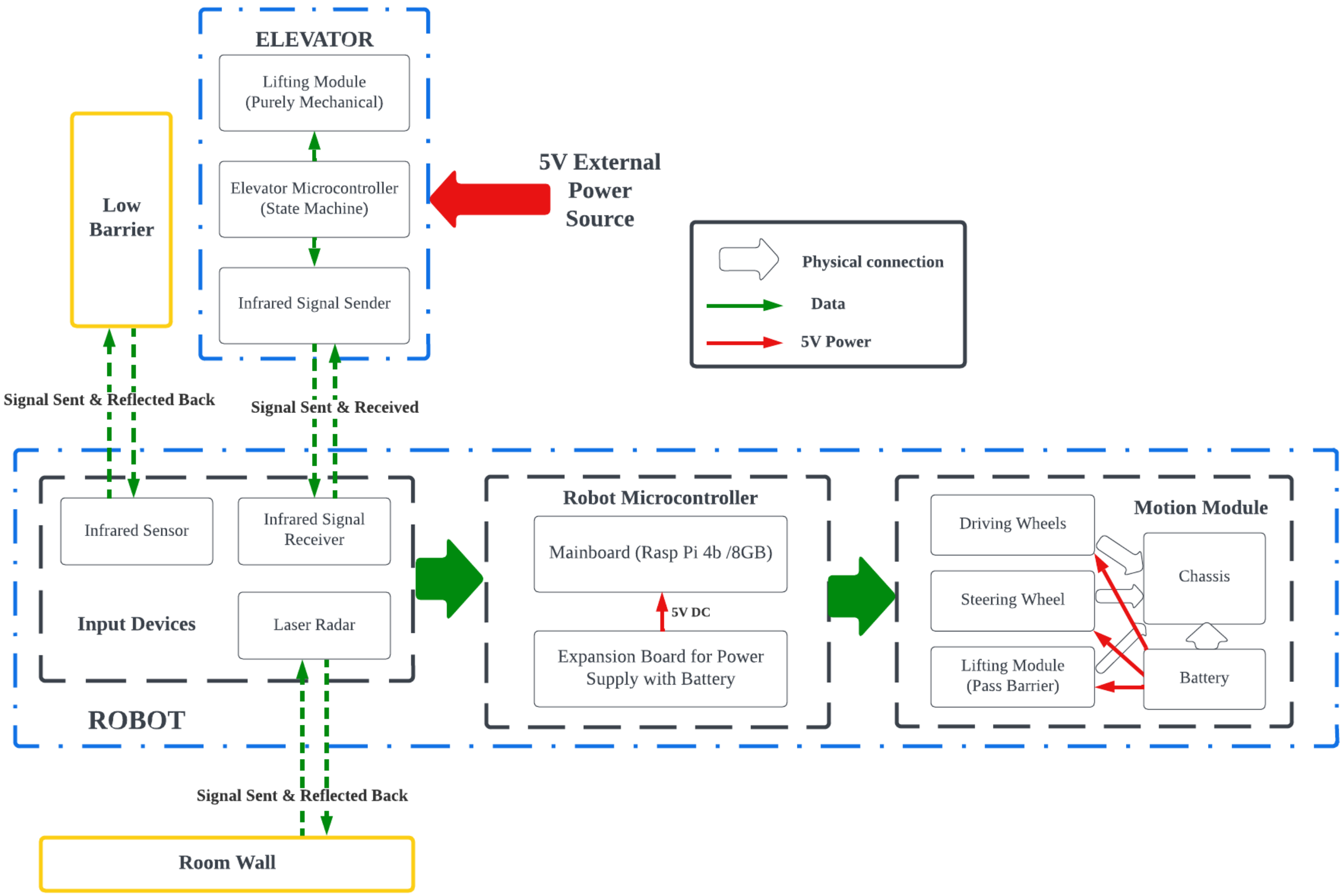

Figure 2: Overall Block Diagram

Figure 2 above shows the overall block diagram of our robot vacuum. Our design has two devices, one robot vacuum and one elevator.

The robot vacuum takes three main steps to do the cleaning work. First, it receives input information from input devices. For example, it receives information about the 2D surrounding environment from the laser radar. Then, it processes information with its microcontroller, a Rasp Pi 4b along with its power supply extension board. Finally, the robot vacuum controls the wheels and the suspension system to have proper motion and satisfy the requirements of our subsystems.

The elevator is much simpler compared to the robot vacuum. When the robot vacuum enters, the elevator will automatically rise and send the robot vacuum to the next floor.

Figure 3 to Figure 6 below show the detailed block diagrams of our subsystem design.

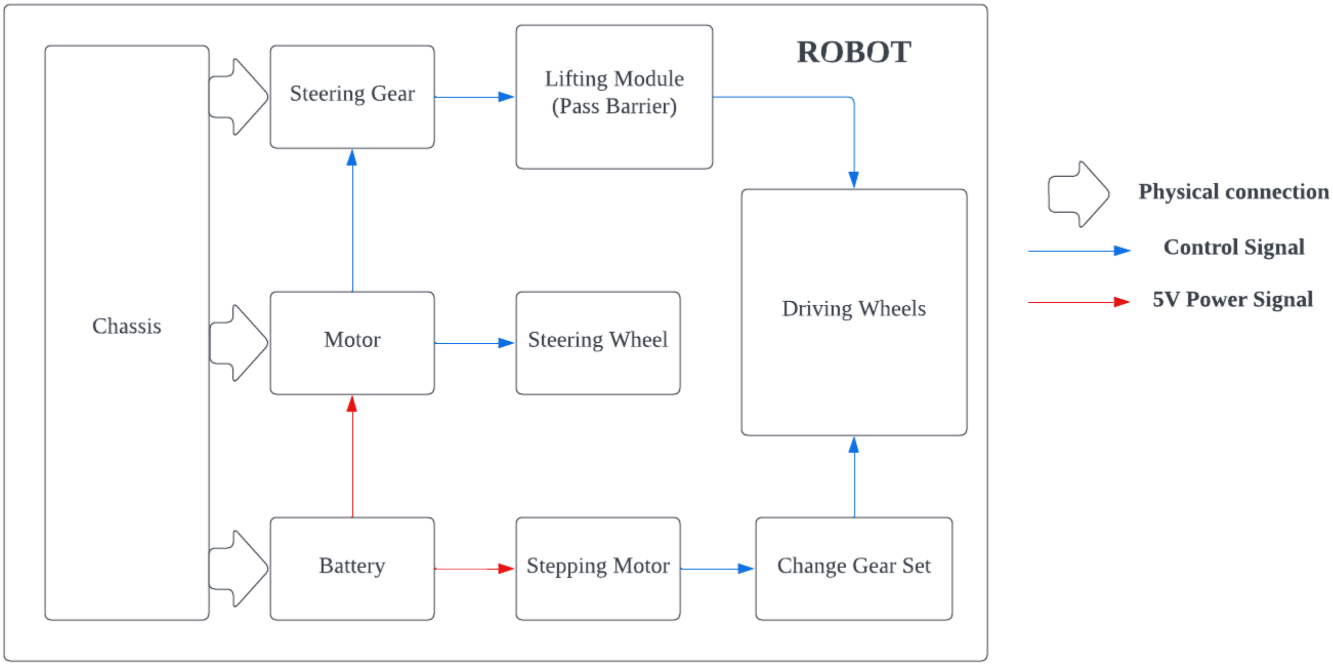

Figure 3: Block Diagram of Anti-fall Steering Subsystem and Robot Motion Control

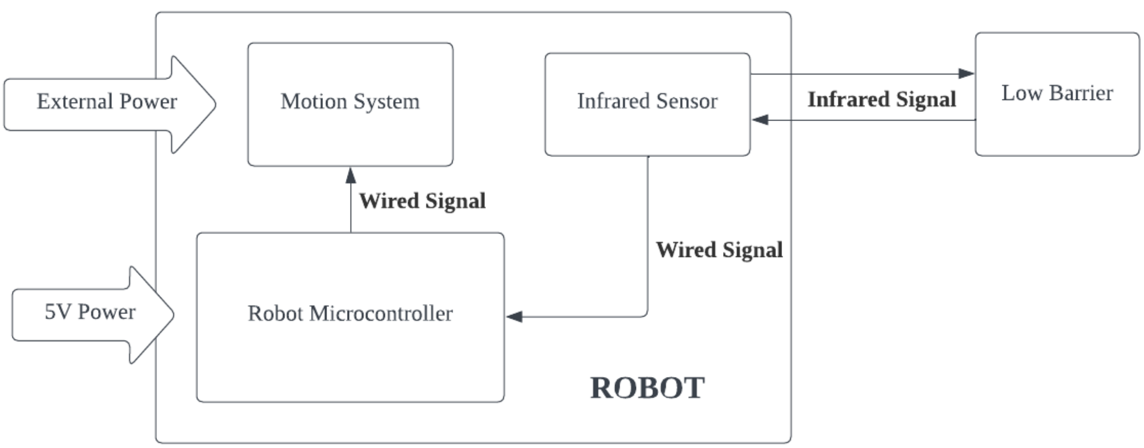

Figure 4: Block Diagram of Low Obstacles Passing Subsystem

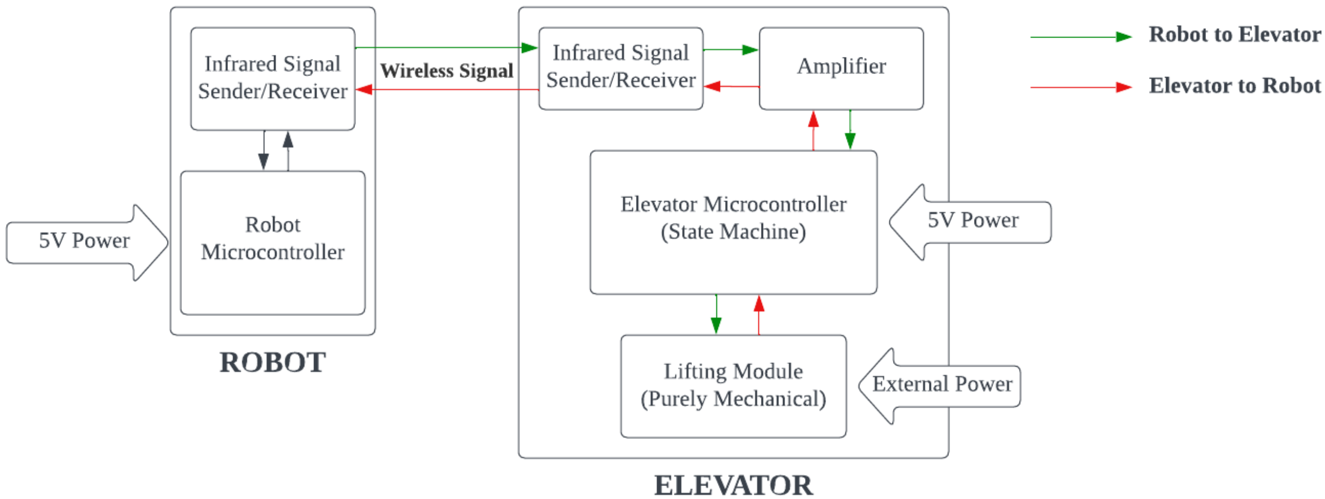

Figure 5: Block Diagram of Elevator Interaction Subsystem

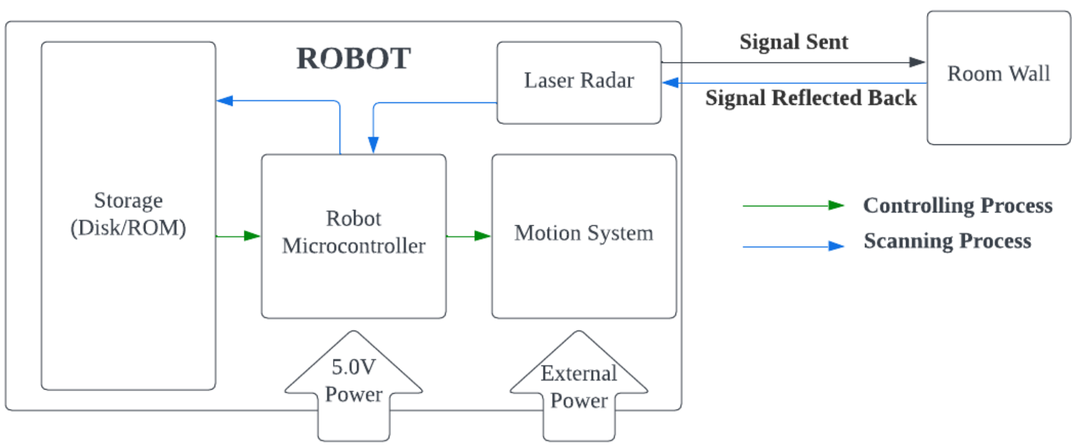

Figure 6: Block Diagram of Effective Path-Finding Subsystem

2.2 Primary Subsystem Design

2.2.1 Anti-fall Steering Subsystem

The *Anti-Fall Steering Subsystem* allows the robot to automatically turn when approaching the edge of stairs, which is a critical safety feature that prevents the robot from falling and causing damage. This functionality is achieved through a completely mechanical structure that does not require any software or programming. The block diagram is shown in Figure 3.

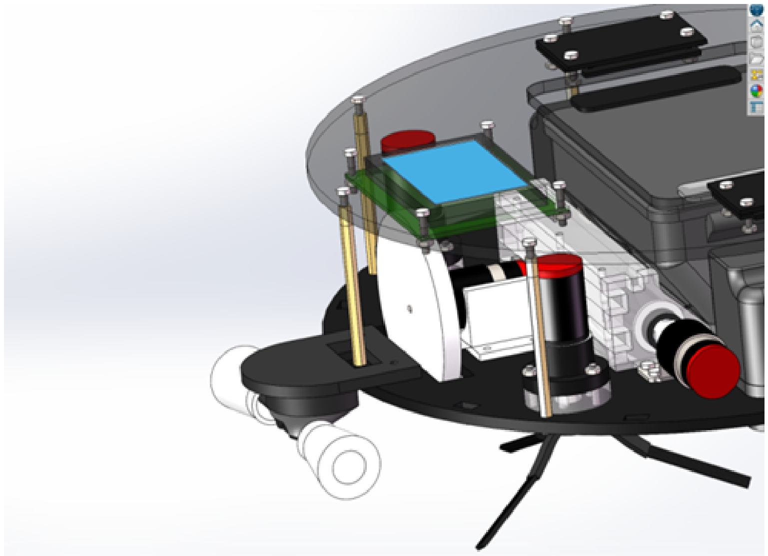

Figure 7: Anti-Fall Subsystem Design 3D Model

As shown in Figure 7, the structure consists of a steering wheel that is positioned perpendicular to the forward direction and two tapered front wheels. The steering wheel is a little higher than other wheels, when the robot vacuum moves normally, the steering wheel does not touch the ground. However, when the robot moves to the edge of the platform and the conical front wheel protrudes out of the platform, its chassis height will decrease, causing the steering wheel to touch the ground, so as to realize steering and avoid falling off the platform.

The purely mechanical structure of this function means that it is highly reliable and does not require any maintenance or software updates. This simplifies the complexity of the code, avoids detection errors caused by the color of the baseboard, and avoids the possibility of electronic failure, compared with the solution of anti-drop function through the sensor, making it an excellent choice for long-term use. Overall, the robot's ability to avoid falling when approaching the edge of stairs is a testament to its advanced design and engineering, which prioritizes safety and reliability above all else.

Requirements	Verification
1) The steering wheel should be able to turn the robot vacuum around with a weight of at least 4kg.	1) Without the control from the microcontroller and input devices, we start with a 4kg robot and let it move off the edge, examining whether it can successfully turn around.
2) When the angle between the edge and the robot vacuum ranges from 45°to 135°, the subsystem works normally and the robot does not fall.	2) We will let the robot approach the edge in different directions, each time noting down the angle degree. The robot should not fall when the angle is between 45°and 135°.

Table 1: Requirement & Verification of Anti-fall Steering Subsystem

2.2.2 Low Obstacles Passing Subsystem

The ability to navigate obstacles is a crucial feature of any robotic cleaning device. However, our robot vacuum has the ability to pass over low thresholds and other obstacles during the cleaning process, ensuring that all areas of the room are effectively cleaned without getting stuck. The block diagram is shown in Figure 4.

The robot's infrared sensor is the first line of defense in detecting any obstacles in front of it. The sensor scans the area and alerts the robot to any obstacles in its path. Once the obstacle is detected, the robot's gear and rack structure comes into play (See Figure 8). This structure is designed to raise the robot's chassis and allow it to pass over the obstacle with ease. The motors that drive the gears and racks work together to ensure the robot's passability, even over uneven surfaces.

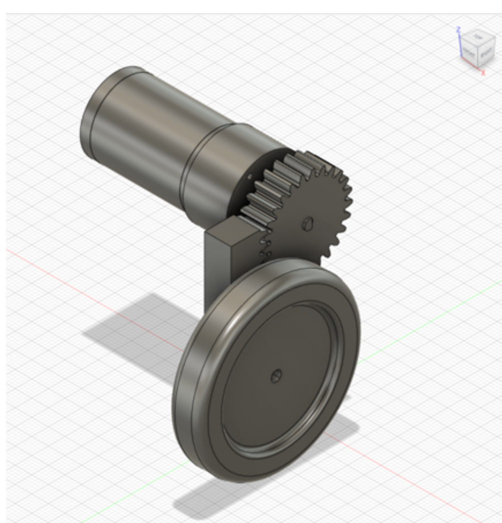

Figure 8: Model of Mechanical Design

When encountering an obstacle, the infrared sensor sends a signal to the motor, and the motor turns the gears, as the motor and gears are fixed position, the rack is restricted to moving up and down, so the rack will move downward in a straight line so that the height of the chassis from the ground will become larger, convenient to pass some small obstacles. This advanced mechanism helps the robot navigate small obstacles and thresholds that could otherwise impede its progress. The ability to navigate obstacles is particularly useful in homes and other environments where there are many small obstacles. The robot's infrared sensor and gear and rack structure enable it to navigate around furniture, rugs, and other small objects without causing any damage to the device or the environment. This makes the cleaning process more efficient and convenient, as the robot can clean larger areas in a shorter amount of time. With the ability to navigate obstacles with ease, the robot can move freely throughout the room, cleaning all areas thoroughly without the need for human intervention.

Requirements	Verification
1) For a robot vacuum with a height of 100mm and a weight of 5kg, a gear with around 25 teeth, a stress angle of around 20 degrees, a module of 1 and a matching rack with a length of around 35 mm can be selected.	1) We run simulations over the process of crossing over objects. Among those simulations, we determine the best gear and rack parameters that make the robot cross over the obstacles smoothly.
2) The robot vacuum should be able to climb over **fixed thresholds** with a height of at most 2cm and a width of at least longer than the width of the robot without getting stuck.	2) We will choose thresholds with sufficient widths and heights of 0.5cm, 1cm, 1.5cm and 2cm to see if the robot can climb over them smoothly.
3) The robot vacuum should be able to pass over **unfixed objects** with a height of at most 2cm and a width of at least shorter than the width of the robot without getting stuck.	3) We will choose small objects with short widths and heights of 0.5cm, 1cm, 1.5cm and 2cm to see if the robot can pass over them smoothly.

Table 2: Requirement & Verification of Low Obstacles Passing Subsystem

2.2.3 Elevator Interaction Subsystem

Nowadays, there are robots in the hotel that can deliver takeaways or service products across multiple floors, all of which take elevators by themselves. We would like to extend this functionality to our robot vacuum, which is useful for the following scenarios:

- There is a high stair that separates the room into two parts.
- The hotel or school that has multiple floors to be cleaned.

By letting the robot vacuum automatically interacts with the elevator or lift, the robot can do multi-level cleaning in one launch. The block diagram is shown in Figure 5.

The robot vacuum will automatically move to the front of the elevator after finishing its cleaning work on one floor since the exact location of the elevator is stored in its internal memory in advance. Then the robot will enter the elevator slowly. Two infrared sensors are placed vertically upwards on the platform of the elevator to detect whether the robot vacuum is fully in the elevator. After confirming this, the elevator will raise the vacuum to the second floor. There is also an infrared emission device installed on the height of the second floor. When the corresponding infrared receiving device placed on the robot vacuum receives the emitted signals, the robot will perceive that it has been sent to the second floor and will leave the elevator to continue its cleaning work on the new floor.

Meanwhile, we will use aluminum profiles and electric slide rails to build a small lifting device to simulate the use of elevator scenarios to complete the demonstration with the robot vacuum. To be specific, we will use 12 aluminum profiles to build a 600mm by 600mm by 800mm square frame, and two vertical parallel slide rails fixed on one side of the square frame, two slide rails to support a square platform.

Requirements	Verification
1) The robot vacuum should reach the designated position in the elevator within 30 seconds from the time the vacuum arrives at the front of the elevator.	1) We measure the time the robot vacuum takes to reach the designated position in the elevator from the time the vacuum arrives at the front of the elevator.
2) The robot vacuum should thoroughly leave the elevator within 10 seconds from the time the elevator reaches the desired floor.	2) We measure the time the robot vacuum takes to thoroughly leave the elevator from the time the elevator reaches the desired floor.

Table 3: Requirement & Verification of Elevator Interaction Subsystem

2.2.4 Effective Path-Finding Subsystem

The robot vacuum will be silly if it cleans the room without any order. To solve this, today's off-the-shelf robot vacuums apply internal path-finding algorithms that can select a path to clean the room with high clean coverage and time efficiency. In our design, as our robot vacuum has the ability to pass low obstacles, we could improve the path-finding algorithm so that for each low obstacle in the room, the robot will analyze the necessity to pass over it. This subsystem consists of two parts: the input device and the micro-controller. This subsystem is also the controller of all other subsystems since we need to generate control signals from the programmable mainboard. The block diagram is shown in Figure 6.

Subsystem Work Flow
Before cleaning, the robot patrols the room to capture the environment with its input devices, including the shape of the room (2D surroundings) and barriers around the room (3D surroundings). Then, with the collected data, the microcontroller builds the map with *gmapping* algorithm. With the map, the robot vacuum runs our modified path-finding algorithm to try to find the most efficient path.

Different from the off-the-shelf robot vacuum products, our modified algorithm takes the existing low barriers into consideration. If the robot comes across low barriers, the software will generate several paths, some pass over them while some bypass them. We give a heuristic standard to the robot to choose the best route among all generated routes.

This subsystem interacts with other subsystems often. First, if the robot decides to pass over the obstacles, the microcontroller will control the mechanical part in Section 2.2.2 to do this. The robot also regards the position of the elevator in Section 2.2.3 as the endpoint of the cleaning path, which will optimize the generated routes for multi-floor cleaning.

Input Devices
We use two kinds of input devices, the range laser radar for 2D surroundings and the infrared sensor from Section 2.2.2 for 3D surroundings.

For 2D surrounding capture, we choose to use RPLIDAR A1M8 range laser radar, whose physical diagram [1] is shown below. We will use a 5V power supply for both the digital system and the motor system.

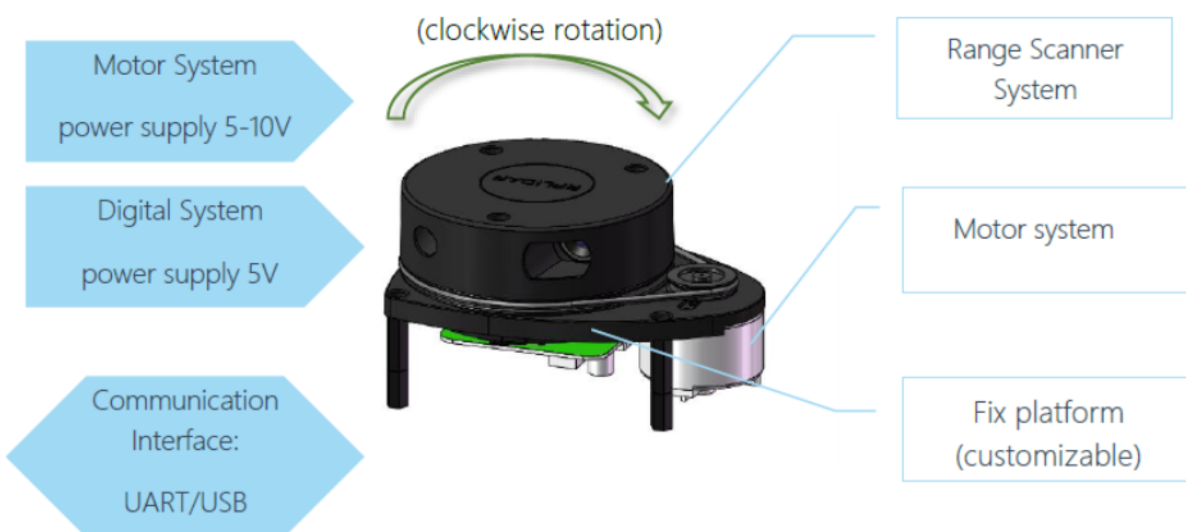

Figure 9: RPLIDAR A1M8 Physical Diagram

The radar will use an optical way (See Figure 10) to measure the distance between the robot vacuum and the surrounding wall from 0.15 to 12 meters, 360 degrees [1]. However, it can only measure the distance horizontally, so we can only get 2D surroundings solely based on that.

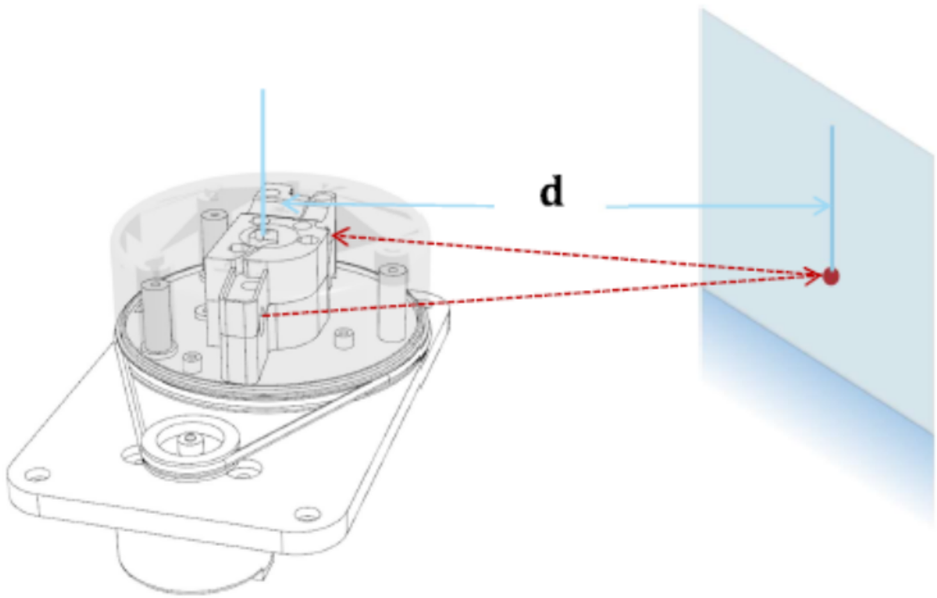

Figure 10: RPLIDAR A1M8 Measuring Theory

For simple 3D surrounding capture, we use the infrared sensor mentioned in Section 2.2.2. When the sensor feels the obstacle that can be passed, the microcontroller will know and note down the position to complete the map.

Microcontroller

There are two choices that are applicable for the mainboard of our microcontroller: Jetson Nano B01 and Rasp Pi. Compare to the Rasp Pi, Jetson Nano B01 is more efficient in graph manipulation, which means it is good at deep learning and AI. Meanwhile, Rasp Pi has a more powerful CPU [2]. Since the purpose of this subsystem is to capture the 2D and 3D surroundings of the unfamiliar room, build maps, and then control the robot vacuum to clean the room, Rasp Pi is the better choice.

We choose Rasp Pi 4b (8GB RAM) [3] as our mainboard (See Figure 11). It runs a Linux system with ROS and we will use the USB interfaces to output the signals to control other subsystems.

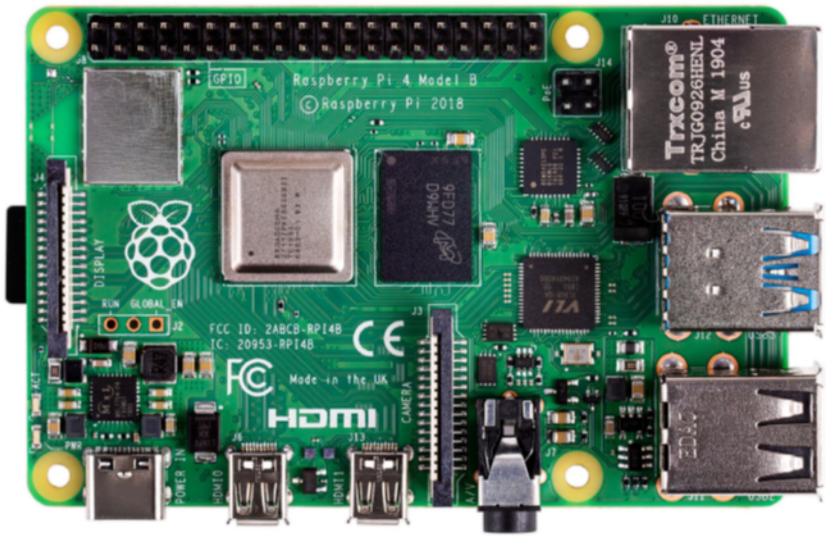

Figure 11: Physical Diagram of Rasp Pi 4b 8GB

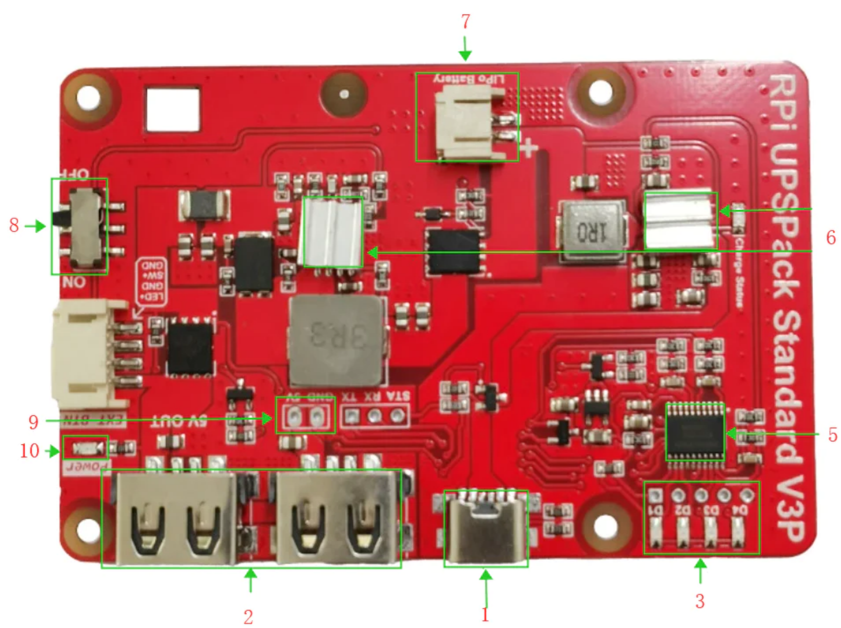

Figure 12: Physical Diagram of Expansion Board UPSPack Standard Power Supply

One big challenge is to provide stable 5V DC power to the mainboard [4], to protect our Rasp Pi from damage, we choose to use an expansion board (See Figure 12). With two 3.7V Lithium batteries as the power source, the expansion board will generate stable 5V DC output for our Rasp Pi [5].

Requirements	Verification
1) The robot shows the existence of low obstacles in the built map.	1) We manually choose an empty room and put some low obstacles, we let the robot patrol and check the generated map.
2) The complexity of our path-finding algorithm should be at least at the same complexity level as the existing algorithm. If this cannot be the case, the computing time shall not exceed 25% of the existing scheme.	2) We will run the original algorithm and our updated algorithm, keeping track of their elapsed running time, and making comparisons.
3) The algorithm the robot vacuum adopts should be able to deal with situations where low obstacles exist, and the efficiency should be improved by at least 5% compared with the existing ones.	3) We will provide one map to the robot and run the original algorithm and our modified algorithm. Then we compare the length of output routes to see the time efficiency (we assume constant time cost for passing over the low obstacles).

Table 4: Requirement & Verification of Effective Path-Finding Subsystem

2.3 Secondary Unit Design

2.3.1 Driving Unit

For this system, two electric motors need to provide enough power to propel the movement of the robot vacuum. Usually, the weight of the robot vacuum is within 5kg and the height is below 100mm, so the motor can not occupy too large volume, nor can the weight be too large. In addition, the size and style of the wheels need to be carefully chosen. Although the McNamm wheel is currently popular on robots to achieve more flexible direction changing, for sweeping robots, it does not need very flexible direction changing ability but pays more attention to energy consumption and endurance, so we choose the common rubber wheel. The wheel size matches the robot size, and a wheel with a diameter of 70mm and a thickness of 16mm is selected as the driving wheel. In addition, we need a programmable circuit board to achieve the left and right wheel rotation at different speeds and based on this to achieve the steering function. The block diagram is shown in Figure 3.

Requirements	Verification
The chosen motors and wheels should be able to assemble inside our robot vacuum, and the overall weight percentage should not exceed 50% of the total weight. The voltage required by a single motor should be no more than 5V.	We will compare the products in the network store and make some estimations on the total weight. The common ones are 42.5mm* 42.5mm* 34mm and the rated voltage is 3.4V, whose weight is 223g. We will make our final test when assembling the robot vacuum.

Table 5: Requirement & Verification of Driving Unit

2.3.2 Cleaning Unit

A vacuuming robot is usually equipped with a round body with a removable dust port and a set of roller brushes at the bottom. We have designed a theoretically feasible cleaning system including a rolling brush, edge brush, dust collecting box, and fan (See Figure 13 and Figure 14 below).

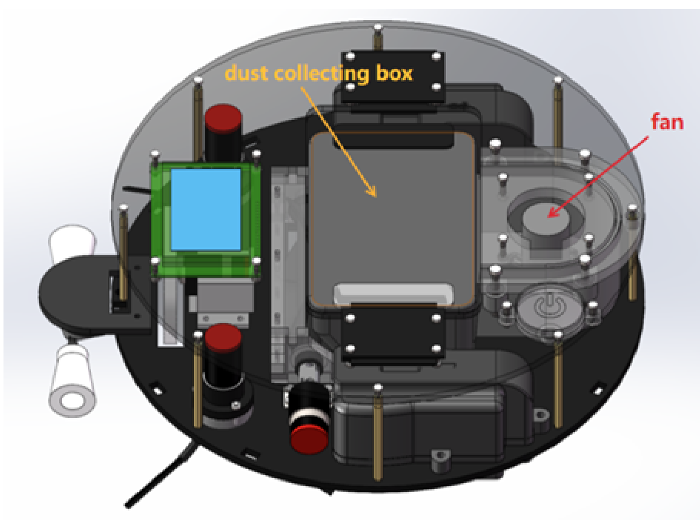

Figure 13: Cleaning Unit Diagram Top View

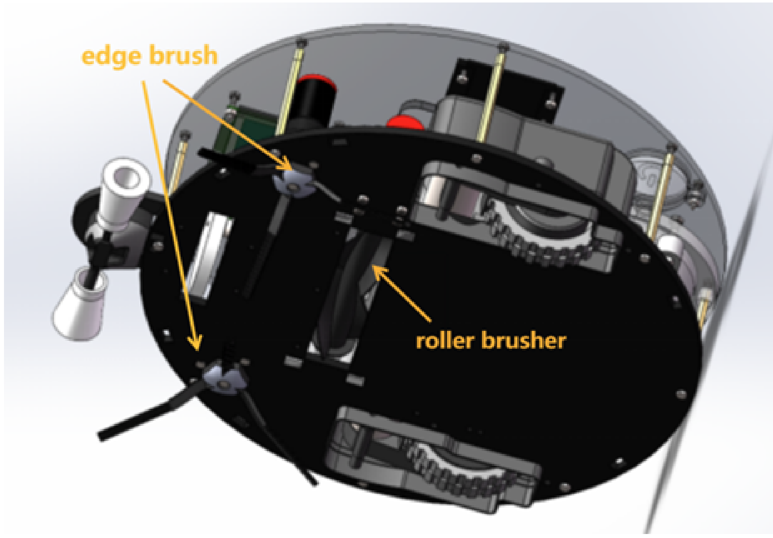

Figure 14: Cleaning Unit Diagram Bottom View

The dust collecting box is located in the center of the robot vacuum, and the vacuum fan is located behind the dust collecting box, forming a front-to-back air duct. A pair of three-leaf brushes are arranged in front of the robot vacuum chassis to clean the ground, and a long roller brush is arranged in the middle of the chassis to assist the vacuum cleaner to collect dust into the dust box. When the robot begins to work, the dust port and brushes begin to rotate, thereby drawing dust and debris from the floor into the robot's dust container or bag. The dust container or bag is usually located at the bottom of the robot and can be easily removed and cleaned.

Since our design focuses on path planning and multi-terrain adaptability, we will not focus too much on the cleaning effect. In fact, it is very difficult to achieve the same effect as the mature sweeping robot on the market.

Requirements	Verification
1) The cleaning unit should have enough suction power to effectively pick up dust, fine sand, hair, and other debris from the floor.	1) We will choose a dirty room to clean and check the dust box after the cleaning work to see if the cleaning unit works normally.
2) The filter of the vacuum cleaner module should be able to effectively filter dust and tiny airborne particles to avoid releasing them into the indoor air.	2) We will examine the cleaning process and see if we can feel the dust flowing into the air.

Table 6: Requirement & Verification of Cleaning Unit

2.4 Tolerance Analysis

2.4.1 Anti-Falling Critical Angle Estimation

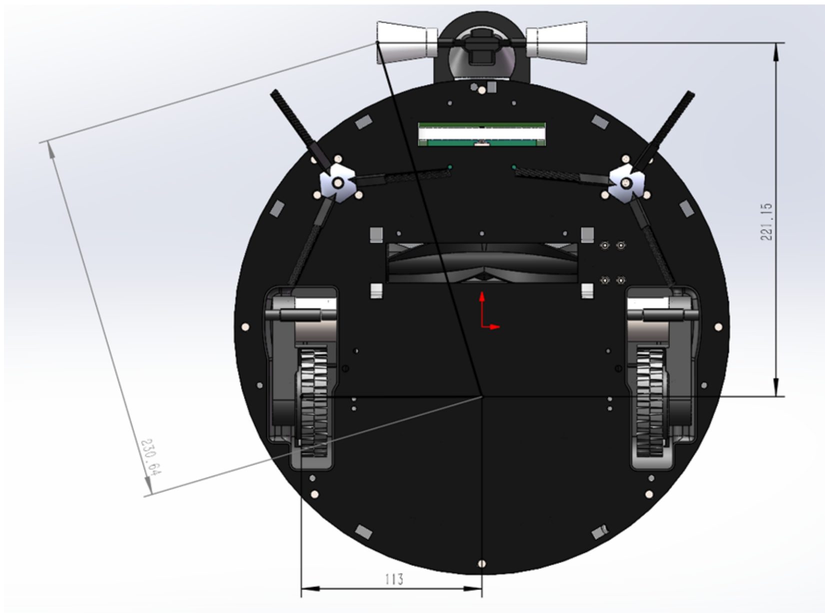

Figure 15: Anti-Falling Critical Angle Estimation Diagram

As it can be seen from Figure 15, the width of the front wheels is shorter than the rear wheels, which means that when the trolley is close to the edge of the platform by a small degree, the rear wheels will fall before the front wheels, and the steering will fail. The critical angle is calculated as the angle between the connection between the front wheel and the rear wheel and the forward direction.

$$
\begin{aligned}
d1 &= \sqrt{230.64^2 - 221.15^2} = 65.48mm \\
d2 &= 113 - 65.48 = 47.52mm \\
L1 &= 221.14mm \\
L2 &= \sqrt{221^2 + d2^2} = 226.05mm \\
\theta &= \arccos L1/L2 = 12.07^\circ
\end{aligned}
$$

If the current structural error rate is found to be too high in the test, we need to consider reducing the critical Angle. Fortunately, the critical Angle can be fixed by increasing the width of the front wheel, which is an easy adjustment, but increasing the width of the front wheel makes it harder for the robot to clean the corners. So we need to find a balance between the two.

2.4.2 Maximum Passing Height Estimation

To calculate the height of the obstacle that a robot vacuum with a raised chassis of 35mm and a wheel diameter of 65mm can pass, we can use the following formula:

$$
\begin{aligned}
&Maximum\ obstacle\ height = (wheel\ diameter/2) + raised\ chassis\ height \\
&Maximum\ obstacle\ height = (65mm/2) + 35mm \\
&Maximum\ obstacle\ height = 67.5mm
\end{aligned}
$$

Therefore, the vacuum cleaner can pass through an obstacle with a maximum height of 67.5 mm.

For the tolerance analysis, we need to consider the potential variations in the dimensions of the vacuum cleaner components that could affect the maximum obstacle height. For example, variations in the size of the wheels or the raised chassis height could impact the maximum obstacle height.

To make the tolerance analysis, we can use the following formula:

$$Allowable\ variation = (Maximum\ obstacle\ height - Minimum\ obstacle\ height)/2$$

Assuming that the minimum obstacle height is 5mm, we can calculate the allowable variation using the following formula:

$$
\begin{aligned}
&Allowable\ variation = (67.5mm - 5mm)/2 \\
&Allowable\ variation = 28.75mm
\end{aligned}
$$

Therefore, the vacuum cleaner's maximum obstacle height can vary by up to 28.75mm due to component variations.

2.4.3 Rack Movement Estimation

To calculate the range of up and down movement of the rack with the gear fixed, we need to consider the pitch of the gear and the pitch of the rack. The pitch of a gear is the distance between adjacent teeth, and the pitch of a rack is the distance between the centers of two adjacent teeth on the gear that the rack engages with.

The pitch of a gear with a modulus of 1 and 25 teeth can be calculated using the formula:

$$Gear\ pitch = \pi/modulus = \pi/1 = \pi$$

The pitch of a rack with a modulus of 1 and a length of 35mm can be calculated using the formula:

$$Rack\ pitch = modulus * (tooth\ count - 1) = 1 * (35/modulus) = 35$$

To calculate the range of up and down movement of the rack with the gear fixed, we need to consider the maximum and minimum values of the backlash, which is the distance between the gear and the rack when they are not in contact. The range of up and down movement of the rack with the gear fixed is twice the maximum backlash.

The maximum backlash can be calculated using the formula:

$$\begin{aligned}
&Backlash = (0.25 * module) + (0.15 * module * (tooth\ count + 2)) \\
&Backlash = (0.25 * 1) + (0.15 * 1 * (25 + 2)) \\
&Backlash = 4.3mm
\end{aligned}$$

Therefore, the range of up and down movement of the rack with the gear fixed is:

$$Range = 2 * backlash = 2 * 4.3mm = 8.6mm$$

For the tolerance analysis, we need to consider the potential variations in the dimensions of the gear and the rack that could affect the maximum backlash. For example, variations in the tooth profile or the stress angle could impact the maximum backlash.

To calculate the tolerance analysis, we can use the following formula:

$$Allowable\ variation = (Maximum\ backlash - Minimum\ backlash)/2$$

Assuming that the minimum backlash is 4mm, we can calculate the allowable variation using the following formula:

$$\begin{aligned}
&Allowable\ variation = (4.3mm - 4mm)/2 \\
&Allowable\ variation = 0.15mm
\end{aligned}$$

Therefore, the maximum backlash can vary by up to 0.15mm due to component variations. This would result in a maximum variation in the range of up and down movement of 0.3mm (twice the allowable variation).

2.5 Other Trivia

Different barriers may have different shapes, if the shape is strange, the infrared sensor may fail to detect the correct height. We expect the robot to pass the barrier of which the highest height is less than 2cm. We allow the robot to try but fail to pass over the obstacles with almost all parts flat but with a sharp structure.

The robot scans the room statically, but new obstacles can be put into the room after scanning. When the robot meets these obstacles on the planned route, we allow the robot to either recompute the route or just simply bypass them. In this case, the path might not be the best, but we accept this deviation.

3 Cost and Schedule

3.1 Cost

All units on cost are RMB (¥) by default.

3.1.1 Labor

According to a report on employment data released by Chinese Education Online [6], fresh graduates with a bachelor's degree in computer science earn about ¥6,800 a month, or ¥42.5 an hour. Graduates majoring in electrical engineering earn about ¥6,300 a month, or ¥39.4 an hour. Fresh graduates of mechanical engineering earn around ¥6,000 a month, or ¥37.5 an hour.

We have 14 weeks this semester. Assuming that each person spends 10 hours on the graduation project every week, we will spend a total of $10*14 = 140$ hours on this project.

Name	Major	Hourly Salary	Hours Needed	Total Cost	Total Cost x 2.5
Tianyu Zhang	ECE	¥42.5	140	¥5,950	¥14,875
Long Chang	ME	¥37.5	140	¥5,250	¥13,125
Zheyi Hang	ME	¥37.5	140	¥5,250	¥13,125
Kailong Jin	EE	¥39.4	140	¥5,516	¥13,790
Total					¥54,915

Table 7: Labor Cost

3.1.2 Parts

Description	Quantity	Manufacturer	Vendor	Cost/Unit	Total Cost
Double-pass Copper Columns (M3*80mm)	20	Zhejiang Bangli Hardware Products Co., Ltd.	1688	¥2.4	¥48
Screws (M3*18mm)	2	Zhejiang Bangli Hardware Products Co., Ltd.	1688	¥1.9	¥3.8
Needle Roller Bearing (6mm*10mm*9mm)	4	Zhejiang Bangli Hardware Products Co., Ltd.	1688	¥3.5	¥14
Aluminum Profile (20*20*400)	8	Zhejiang Bangli Hardware Products Co., Ltd.	1688	¥7.4	¥59.2
Aluminum Profile (20*20*800)	4	Zhejiang Bangli Hardware Products Co., Ltd.	1688	¥14.8	¥59.2
Motor-R300C (0.05A, 1.5-6V)	1	Ningbo Zhenhaigewa Transmission Equipment Co., Ltd.	1688	¥8.2	¥8.2
Motor-25GA-370 (0.45A, 6V)	2	Ningbo Zhenhaigewa Transmission Equipment Co., Ltd.	1688	¥23	¥46
Lead Screw Electric Guide With Motor (800mm)	1	Ningbo Zhenhaigewa Transmission Equipment Co., Ltd.	1688	¥435	¥435
3D Printing Consumables (PLA, 1kg)	2	Hangzhou Weidi Shang Innovation Technology Co., Ltd.	1688	¥62	¥124
Acrylic Sheet (50mm*50mm*3mm)	2	Hangzhou Weidi Shang Innovation Technology Co., Ltd.	1688	¥33.5	¥67
Total					¥864.4

Table 8: Mechanical Parts Cost

Description	Quantity	Manufacturer	Vendor	Cost/Unit	Total Cost
MIK-AL-10 Infrared Sensor	2	Asmik Sensor Technology Co.	TaoBao	¥10	¥20
MIK-AL-20 Infrared Emission & Receiving Devices Pair	1	Asmik Sensor Technology Co.	TaoBao	¥30	¥30
Rasp Pi 4b/8GB	1	Raspberry Pi (Trading) Ltd.	Yahboom	¥1,429	¥1,429
SanDisk TF Card 64GB	1	Western Digital	Yahboom	¥32	¥32
Rplidar A1M8	1	Shanghai Slamtec Co., Ltd.	Yahboom	¥498	¥498
Rasp Pi 4b 21700 Power Pack	1	Western Digital	TaoBao	¥157	¥157
TF Card Reader	1	UGREEN	JingDong	¥45	¥45
Micro HDMI to HDMI Data Line	1	UGREEN	JingDong	¥25	¥25
USB 3.0 Data Line	1	UGREEN	JingDong	¥22.9	¥22.9
Type-C to USB Adapter	1	UGREEN	JingDong	¥27.9	¥27.9
Type-C to HDMI Adapter	1	UGREEN	JingDong	¥79	¥79
Total					¥2,365.8

Table 9: Digital Parts Cost

3.1.3 Grand Total

Section	Total
Labor	¥54,915
Mechanical Parts	¥864.4
Digital Parts	¥2,365.8
Grand Total	¥58,145.2

Table 10: Grand Total Costs

3.2 Schedule

Week	Task	Responsibility
03/20/2023	Finish Design Document.	All
	Design low obstacle passing subsystem circuit part.	Kailong Jin
	Study existing path-finding algorithms and think about how to improve them.	Tianyu Zhang
	Assemble our robot vacuum.	Long Chang
	Assemble our robot vacuum.	Zheyi Hang
03/27/2023	Make the circuit board for the suspension system.	Kailong Jin
	Make the robot vacuum work based on existing algorithms.	Tianyu Zhang
	Design anti-fall steering system mechanical part.	Long Chang
	Design low obstacle passing subsystem mechanical part.	Zheyi Hang
04/03/2023	Integrate the improved suspension system to robot vacuum.	Kailong Jin
	Find how to improve path-finding algorithms.	Tianyu Zhang
	Make the mechanical structure for the anti-fall steering system.	Long Chang
	Make the mechanical structure for low obstacle passing subsystem.	Zheyi Hang

04/10/2023	Design the signal transmission between the robot and elevator.	Kailong Jin
	Start programming our modified path-finding algorithm.	Tianyu Zhang
	Integrate anti-fall steering system to robot vacuum.	Long Chang
	Integrate the improved suspension system into the robot vacuum.	Zheyi Hang
04/17/2023	Design the circuit board for the elevator.	Kailong Jin
	Finish programming the path-finding algorithm.	Tianyu Zhang
	Design the elevator mechanical part.	Long Chang
	Design the elevator mechanical part.	Zheyi Hang
04/24/2023	Implement the elevator interaction subsystem.	Kailong Jin
	Implement the effective path-finding subsystem.	Tianyu Zhang
	Implement the elevator interaction subsystem.	Long Chang
	Implement the elevator interaction subsystem.	Zheyi Hang
05/01/2023	Fix bugs & Integration testing & Prepare Mock Demo.	All
	Fix bugs & Integration testing on the elevator interaction subsystem.	Kailong Jin
	Fix bugs & Integration testing on the effective path-finding subsystem.	Tianyu Zhang
	Fix bugs & Integration testing on the anti-fall steering subsystem.	Long Chang
	Fix bugs & Integration testing on the low obstacle passing subsystem.	Zheyi Hang

05/08/2023	Prepare final presentation.	All
	Working on the final presentation.	Kailong Jin
	Working on the final presentation.	Tianyu Zhang
	Working on the final presentation.	Long Chang
	Working on the final presentation.	Zheyi Hang
05/15/2023	Finish final report & Team Evaluation.	All
	Working on the final report.	Kailong Jin
	Working on the final report.	Tianyu Zhang
	Working on the final report.	Long Chang
	Working on the final report.	Zheyi Hang

Table 11: Project Schedule and Task Allocation

4 Ethics and Safety

4.1 Ethics

Privacy:
Robot vacuums should be designed to respect the privacy of individuals. This means that they should not collect or transmit personal data without the explicit consent of the individual. If data is collected, it should be stored securely and deleted when it is no longer necessary. This is in compliance with ACM Code of Ethics and Professional Conduct Clause 1.6 Respect privacy [7].

Safety:
Robot vacuums should be designed to prioritize safety. This means that they should be equipped with safety features to prevent accidents, and should be tested rigorously to ensure that they do not pose a risk to individuals or property.

Transparency:
Robot vacuums should be designed with transparency in mind. This means that individuals should be informed about what data is being collected and how it will be used. In addition, any limitations or potential risks associated with the device should be clearly communicated. This is in accordance with ACM Code of Ethics and Professional Conduct Clause 1.2 Avoid harm [7].

Accessibility:
Robot vacuums should be designed to be accessible to all individuals, regardless of their physical or cognitive abilities. This means that they should be easy to use and operate, and should be designed with universal design principles in mind. This is in conformity with ACM Code of Ethics and Professional Conduct Clause 1.4 Be fair and take action not to discriminate [7].

In addition to these key principles, the code of ethics for robot vacuums should also include guidelines for testing and certification, as well as guidelines for accountability and responsibility. This can help ensure that manufacturers and users are held accountable for any ethical lapses that may occur.

4.2 Safety

Risk of Collision:
These devices are designed to navigate around obstacles and furniture, but they can still accidentally collide with objects or people. This can result in damage to the device, as well as potential injury to individuals or damage to property. To mitigate this risk, robot vacuum should be equipped with sensors and other safety features to help prevent collisions.

Risk of Entanglement:
Robot vacuums typically have brushes or other mechanisms that can become entangled in cords, rugs, or other items on the floor. This can cause the device to become stuck or

damaged, and can also pose a risk of injury to individuals or pets. To address this concern, robot vacuums should be designed with safety features to prevent entanglement, such as automatic shutoffs or sensors that detect when the device is stuck.

Noise Standard:
According to OSHA standard 29 CFR 1910.95 [8], the noise level of Robot vacuums should be below 85 decibels, and appropriate measures must be taken to protect employees from the effects of noise.

Dust and Chemicals:
Robot vacuums used for cleaning up dust and chemicals must comply with OSHA standards, including 29 CFR 1910.1000 for air contaminants and 29 CFR 1910.134 [8] for respiratory protection. Robot vacuums must effectively remove dust and chemicals and appropriate measures must be taken to protect employees from exposure to these hazardous materials.

Electric Shock or Fire:
Robot vacuums are electrical devices, and as such, they can pose a risk of electric shock or fire if not used properly or if there are defects in the device. To mitigate this risk, robot vacuums must comply with OSHA electrical safety standards [8], including 29 CFR 1910.303 for electrical systems design and 29 CFR 1910.304 for wiring methods.

Overall, the safety concerns for our robot vacuum can be addressed through careful design and testing, as well as clear communication to users about proper use and potential risks. By prioritizing safety in the design and use of these devices, we can ensure that they are a safe and useful addition to our homes.

References

[1] *Rplidar a1-low cost 360 degree laser range scanner-introduction and datasheet*, A1M8, Rev. 3.0, Shanghai Slamtec Co., Ltd., Oct. 2020. [Online]. Available: https://bucket-download.slamtec.com/d1e428e7efbdcd65a8ea111061794fb8d4ccd3a0/LD108_SLAMTEC_rplidar_datasheet_A1M8_v3.0_en.pdf (visited on 03/22/2023).

[2] AIwonder. "What is the difference between Raspberry Pi and Jetson Nano?" (Oct. 2021), [Online]. Available: https://blog.csdn.net/AIwonder/article/details/120907204 (visited on 03/24/2023).

[3] *Raspberry pi 4 computer model b*, 4b/8GB, Raspberry Pi Trading Ltd., May 2020. [Online]. Available: https://static.raspberrypi.org/files/product-briefs/200521+Raspberry+Pi+4+Product+Brief.pdf (visited on 03/22/2023).

[4] *Datasheet raspberry pi 4 model b*, 4b/8GB, Rev. 1, Raspberry Pi Trading Ltd., Jun. 2019. [Online]. Available: https://datasheets.raspberrypi.com/rpi4/raspberry-pi-4-datasheet.pdf (visited on 03/22/2023).

[5] MakerFocus. "MakerFocus Raspberry Pi Expansion Board UPSPack Standard Power Supply -RPi V3P." (2023), [Online]. Available: https://www.makerfocus.com/products/raspberry-pi-expansion-board-ups-pack-standard-power-supply (visited on 03/22/2023).

[6] C. E. O. (EOL). "The 2022 Blue Book of Employment: Revealing the Average Monthly Income of College Graduates." (Jun. 2022), [Online]. Available: https://www.eol.cn/news/yaowen/202206/t20220614_2231533.shtml (visited on 03/21/2023).

[7] ACM. "ACM Code of Ethics and Professional Conduct." (2018), [Online]. Available: https://www.acm.org/code-of-ethics (visited on 03/08/2023).

[8] Osha.gov. "Law and Regulations." (2023), [Online]. Available: https://www.osha.gov/laws-regs (visited on 03/21/2023).