ECE 445

SENIOR DESIGN LABORATORY

PROJECT PROPOSAL

Robot Vacuum

Team #9

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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 cross low 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 evolves and price decreases, robot vacuums are becoming more and more popular. At the same time, they gradually evolved from having only a single sweeping function to having a certain level of intelligence, including identifying room type, video monitoring pet activities, and even family calls. However, from our daily experience in the use of robot vacuums, there still exist many problems. One is that the robot vacuum may fall from a high plane without notice and break. The other is that it may get stuck when passing through rough and uneven ground. Also, it cannot realize cross-floor cleaning. The last problem is that the path-finding algorithm can still be improved. To further reduce the work that workers need to do personally and increase the reliability of the robot vacuum, the four problems above are urgent to be solved.

1.2 Solution

We propose an advanced version of the robot vacuum that can tackle these four problems. Specifically, we design four separate subsystems and then integrate them into the existing robot vacuum. First, 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. Second, the suspension structure will be improved to give the robot vacuum better pass ability. To be specific, the chassis of the vacuum will automatically get raised when the infrared sensors notice low obstacles approaching. This is our second subsystem named the low obstacle passing subsystem. Third, the elevator interaction subsystem allows the robot vacuum to call the elevator to send itself to the next floor by realizing signal transmission between the two. In this way, it can perform multi-floor sweeping operations. In addition, 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 may constitute the fourth subsystem called the effective path-finding subsystem.

1.3 High-Level Requirements List

- The robot vacuum should be able to pass thresholds or obstacles 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 10% 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 clean work.

1.4 Visual Aid

As shown below, Figure 1 illustrates the overall physical appearance and Figure 2 depicts the internal structures of robot subsystems.

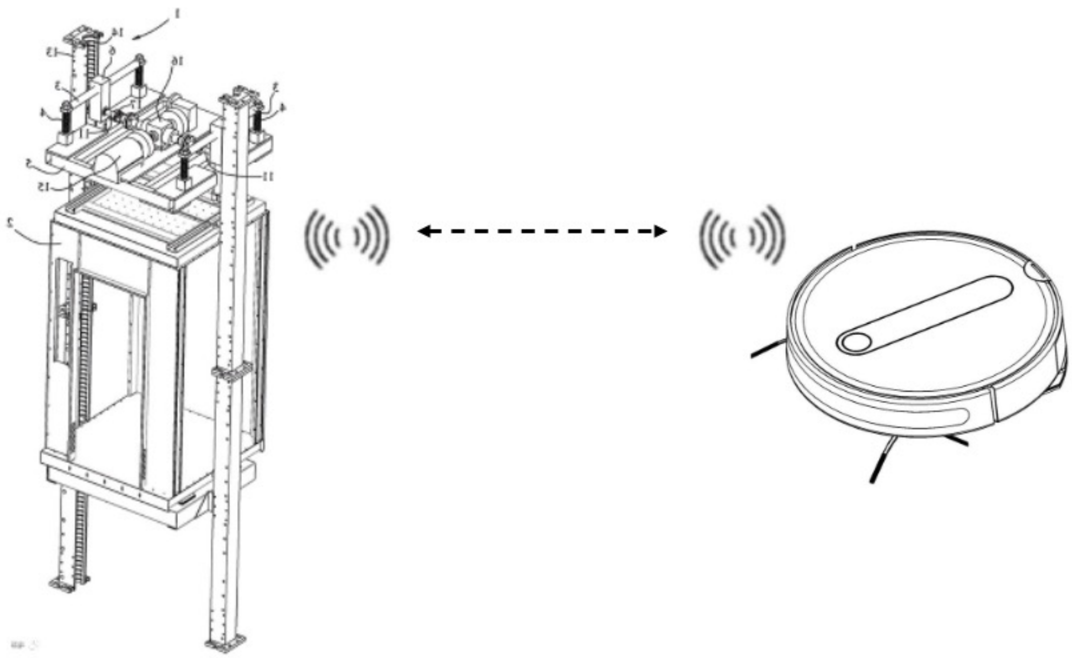

Figure 1: Overall Physical Design Diagram

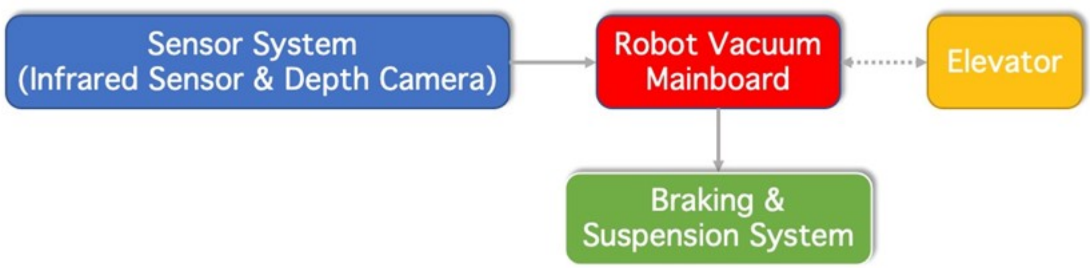

Figure 2: Robot Physical Design Diagram

2 Design

2.1 Block Diagram

Figure 3 to Figure 6 show the main block diagrams of our design.

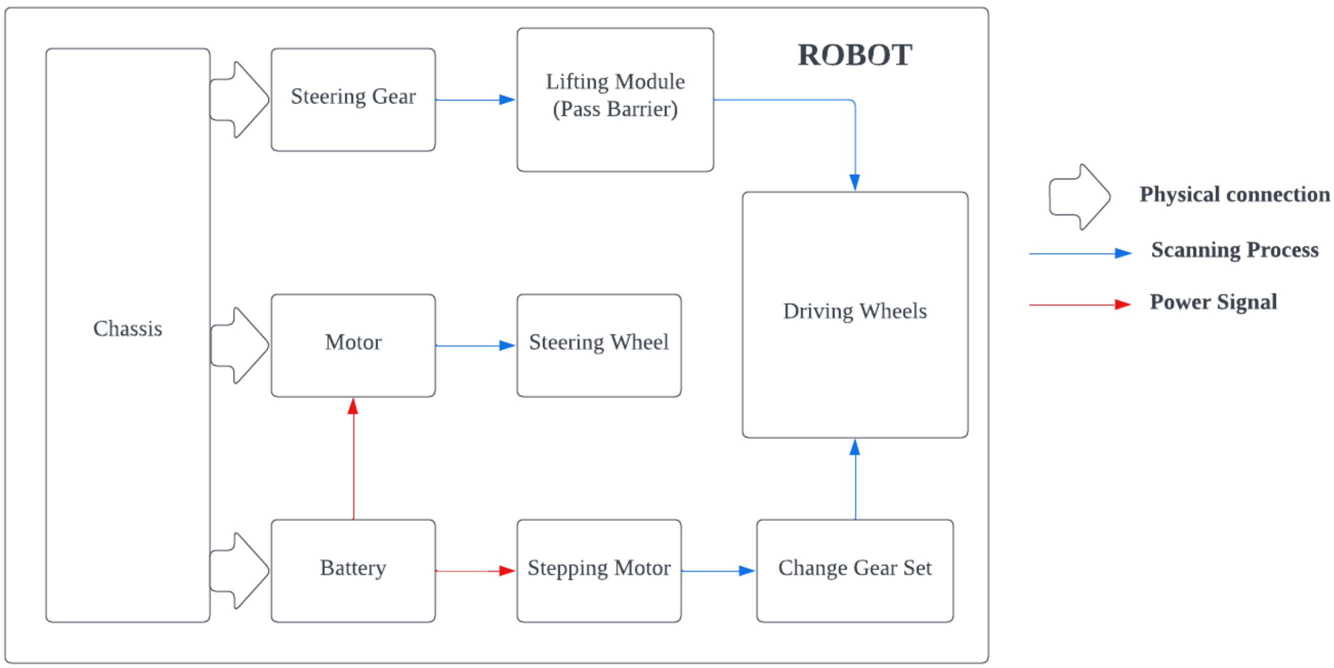

Figure 3: Block Diagram of Anti-fall Steering Subsystem and Robot Motion Control

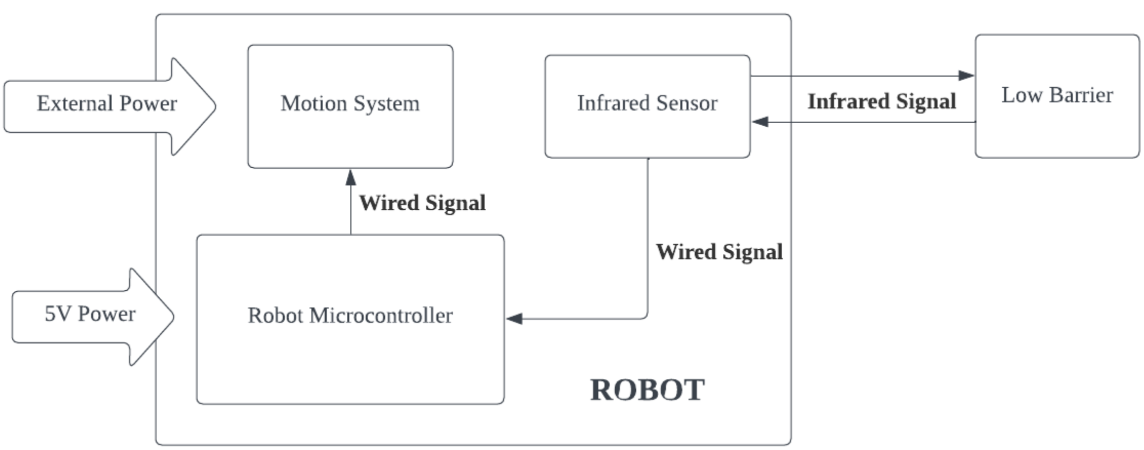

Figure 4: Block Diagram of Low Obstacles Passing Subsystem

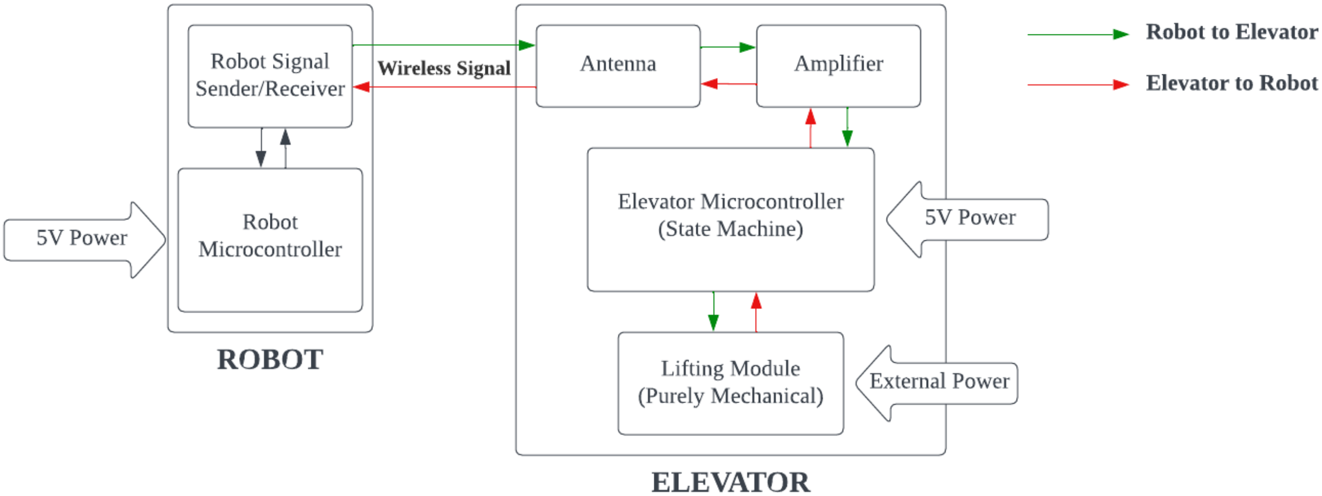

Figure 5: Block Diagram of Elevator Interaction Subsystem

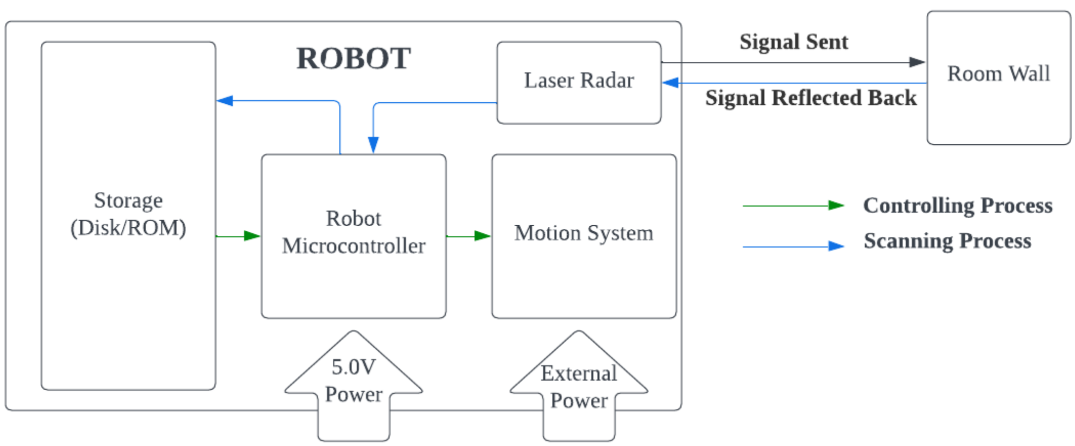

Figure 6: Block Diagram of Effective Path-Finding Subsystem

2.2 Subsystem Overview

As illustrated in Figure 1, the complete system consists of two parts, the robot subject and the matching elevator. When the robot finishes cleaning one floor, it will move toward the elevator and send signals to call the elevator to lift it up to the next floor. For demonstration purposes, we only build a simple lift that can lift the robot up. Figure 2 shows the robot itself, which is the main part of our design. It has four subsystems, together controlling other peripherals to do the driving and cleaning work. As mentioned in Section 1.2, the four subsystems are *Anti-fall Steering Subsystem*, *Low Obstacles Passing Subsystem*, *Elevator Interaction Subsystem* and *Effective Path-Finding Subsystem*. In the next paragraphs, we describe all the subsystems and peripherals in detail.

1. **Subsystem. Anti-fall Steering**
   It allows the robot to automatically turn when it approaches the edge of stairs to avoid falling and this function is completely mechanical and does not require software. The function is based on a purely mechanical structure, with a steering wheel that is perpendicular to the forward direction to achieve steering at the edge of the step.

2. **Subsystem. Low Obstacles Passing**
   This allows the robot to pass low thresholds or obstacles to avoid getting stuck during the cleaning process. In this process, the infrared sensor will be used to detect whether there is an obstacle in front, and the robot will use the steering gear and CAM structure to raise the chassis to pass the obstacle.

3. **Subsystem. Elevator Interaction**
   This subsystem is designed for multi-floor cleaning. An assorted simple lift will be made with an antenna to exchange signals to lift up/down the robot. A state machine is embedded in the elevator to control its behavior and send signals back to the robot. For the robot, the microcontroller will manipulate the signals and decide if the robot should wait or keep cleaning.

4. **Subsystem. Effective Path-Finding**
   This subsystem tells the robot how to find the most effective path for cleaning the room. Before cleaning, we will let the robot patrol inside the room to collect and store the 2D/3D surrounding information using a laser radar. Then the robot uses the improved path-finding algorithm to generate the desired path while taking the low obstacles into consideration. That means the robot will make a decision on whether to pass the barrier or bypass it and choose the one with higher efficiency.

5. **Peripheral. Driving**
   The drive unit uses two independent 5V DC stepper motors to control the two driving wheels, which achieve the steering function through the speed difference. The driven wheel is only used for support.

6. **Peripheral. Cleaning**
   The unit has the function of wiping the floor and vacuuming. The dust collection 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.

2.3 Subsystem Requirements

2.3.1 Subsystem. Anti-fall Steering

Description:
The robot's ability to automatically turn when approaching the edge of stairs is a critical safety feature that prevents it from falling and causing damage. This function is achieved through a completely mechanical structure that does not require any software or programming. The robot's design incorporates a steering wheel that is positioned perpendicular to the forward direction, allowing for precise steering at the edge of a step. This mechanism works by detecting when the robot is approaching the edge of the stairs and automatically activating the steering mechanism to turn the robot away from the edge. This design ensures that the robot is always stable and secure on any surface, making it ideal for use in environments where safety is a top priority. The purely mechanical structure of this function also means that it is highly reliable and does not require any maintenance or software updates, 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. The block diagram is shown in Figure 3.

Requirements	Verification
The single anti-fall steering wheel has a diameter of about 60mm*16mm thickness, which normally does not touch the ground.	Since this part is purely mechanical, we generally use M3/M5 type screws and other standard types of bearings.
Screws and bearings are used to fix it to the chassis and to fix it to the motor through the bearings.	The reliability of this unit needs to be tested experimentally.

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

2.3.2 Subsystem. Low Obstacles Passing

Description:
The ability to navigate obstacles is a crucial feature of any robotic cleaning device. The unit in question enables the robot to detect and pass low thresholds and other obstacles during the cleaning process, ensuring that it can effectively clean all areas of the room without getting stuck. The process starts with the robot's infrared sensor, which scans the area in front of the robot to detect any obstacles. If an obstacle is detected, the robot uses its advanced steering gear and CAM structure to lift the chassis of the robot and pass over the obstacle. The steering gear and CAM structure work together to ensure that the robot's movement is smooth and stable, even when passing over uneven surfaces. This feature is particularly useful in homes and other environments where there may be small obstacles or thresholds that could impede the robot's progress. By using the infrared sen-

sor and advanced CAM structure, the robot can easily navigate these obstacles without getting stuck or causing any damage to the device or the environment. Moreover, this unit also makes the cleaning process more efficient and convenient by allowing the robot to 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. The block diagram is shown in Figure 4.

Requirements	Verification
For a robot vacuum with a height of 100mm and a weight of 5kg, a CAM with a diameter of about 50mm and a height of 10-15mm can be selected. A lightweight material such as aluminum alloy is used for the suspension system, and extensive tests and simulations are conducted to ensure the stability and smoothness of the robot.	The angle and shape of the CAMs also need to be adjusted to the design and needs of the robot to ensure that the robot can pass smoothly over obstacles and uneven ground. This requires extensive testing and simulation to determine the best CAM parameters. The robot's suspension system should be lightweight, durable and easy to maintain to ensure the long-term stable operation of the robot.

Table 2: Requirement & Verification of Subsystem. Low Obstacles Passing

2.3.3 Subsystem. Elevator Interaction

Description:
This subsystem's functionality is useful for the following scenarios: There is a high stair that separates the room into two parts. The hotel or school 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. Typically, when the robot finishes cleaning one floor, it will move onto the elevator and ask the elevator to lift it up/down by sending signals. Once the antenna on the elevator receives that signal, its state changes and starts lifting the robot up/down. Once the elevator reaches the next level, it tells the robot to keep cleaning. So with the wireless signal exchange, the robot moves to the upper or lower floors and continues working. The block diagram is shown in Figure 5.

Requirements	Verification
The robot can move onto the elevator or move to its direct front during cleaning.	A. We test this by verifying whether the robot can move toward the elevator in the algorithm simulation. B. We test this algorithm in a real room and elevator.
The process of lifting up/down is smooth, the robot does not get stuck when entering and exiting the elevator.	A. We perform a simulation to test the correctness of the elevator state machine by sending the corresponding signals once at a time. B. There will be an outer frame on the demo elevator, we will examine if the robot can enter and exit the elevator without touching the outer frame.

Table 3: Requirement & Verification of Subsystem. Elevator Interaction

2.3.4 Subsystem. Effective Path-Finding

Description:
Since our robot vacuum has the ability to pass low obstacles, we could also apply this to improve the path-finding algorithm. In specifics, we will upgrade the existing path-finding algorithm so that for each low barrier in the room, the robot will analyze the necessity to pass over it. This subsystem is software only, which will be done on a programmable chip. This subsystem is also the controller of all other subsystems since we need to generate control signals from the programmable chip. The block diagram is shown in Figure 6.
Before cleaning, the robot will patrol the room to capture the environment with its laser radar, including the shape of the room (2D surrounding) and barriers around the room (3D surrounding). Then, with the collected data, the robot runs the algorithm to try to find the most efficient path. For 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.

Requirements	Verification
The robot will take the existence of low obstacles into consideration and choose the correct path based on that.	We manually choose an empty room and put some low obstacles that do not change the most efficient path, we see if the robot passes them rather by-passes them.
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.	A. We will calculate the complexity of both algorithms and compare them. B. We will run the original algorithm and our updated algorithm, keeping track of their elapsed running time, and making comparisons.

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

2.3.5 Peripheral. Driving

Description:
For this system, two electric motors need to provide enough power to propel the movement of the vacuum robot. Usually, the weight of the vacuum robot 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
A single motor size needs to be less than 50mm*50mm*50mm and a single motor weight should be less than 250g. The voltage required by a single motor: no more than 5V. The size of a single wheel should be about 70mm diameter *16mm thickness. Programmable circuit board, need to control the motor speed of two wheels respectively.	There are many optional motors in the network store. The common ones are 42.5mm* 42.5mm* 34mm and the rated voltage is 3.4V, whose weight is 223g. The wheels are also very optional in size and can be 3D printed. Wheel speed control can be achieved using the simplest Arduino-programmed circuit board.

Table 5: Requirement & Verification of Peripheral. Driving

2.3.6 Peripheral. Cleaning

Description:
A vacuuming robot is usually equipped with a round body with a removable dust port and a set of roller brushes on the bottom. 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.

Requirements	Verification
Motor parameters: The power of the motor is usually between 10 and 100 watts, higher power usually means more suction power and higher cleaning efficiency.	Suction strength: The vacuum cleaner module should have enough suction power to effectively pick up dust, fine sand, hair and other debris from the floor. You can test the robot by placing it on different floors to compare its suction strength and effectiveness.
Rotating brush head parameters: The size of the rotating brush head is usually between 10 and 20 cm. Some high-end robots are also equipped with rotating brush heads with adjustable height and adaptive rotation speed to accommodate different types of floors and cleaning tasks.	Cleaning range: The vacuum cleaner module should be able to clean hard-to-reach places such as corners and edges.
Dust collection box size: The size of the dust collection box usually ranges between 0.3 and 1 liter. Larger dust collection boxes can work longer and reduce the number of interventions during cleaning.	Filter: The filter of vacuum cleaner module should be able to effectively filter dust and tiny airborne particles to avoid releasing them into the indoor air.

Table 6: Requirement & Verification of Peripheral. Cleaning

2.4 Tolerance Analysis

The anti-drop function needs to focus on the design of the position of the steering wheel. It must ensure that the center of gravity of the robot is between the steering wheel and the two driving wheels, or the robot will fall before the steering wheel works.

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.

There may be interference between the driven wheel and the brush. It is necessary to consider whether the brush can be used to replace the driven wheel to achieve support or reduce the size of the driven wheel.

3 Ethics and Safety

3.1 Ethics

Privacy:
Robot vacuum cleaners 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 [1].

Safety:
Robot vacuum cleaners 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 vacuum cleaners 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 [1].

Accessibility:
Robot vacuum cleaners 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 [1].

In addition to these key principles, the code of ethics for robot vacuum cleaners 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.

3.2 Safety

One of the primary safety concerns for robot vacuum cleaners is the 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 cleaners should be equipped with sensors and other safety features to help prevent collisions.

Another safety concern is the risk of entanglement. Robot vacuum cleaners 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 vacuum cleaners should be designed with safety features to prevent entanglement, such as automatic shutoffs or sensors that detect when the device is stuck.

In addition to these concerns, there is also the potential for electric shock or fire. Robot vacuum cleaners 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 vacuum cleaners should be designed with safety features such as automatic shutoffs or surge protectors to prevent electrical hazards.

Overall, the safety concerns for robot vacuum cleaners 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] ACM. (2018). "ACM Code of Ethics and Professional Conduct," [Online]. Available: https://www.acm.org/code-of-ethics (visited on 03/08/2023).