High-Level Design

1.1 Design goals and objectives

The primary objective of this project is to design and build a robotic vacuum cleaner that can effectively clean approximately 1000 square feet of area in a single charge. The robotic vacuum cleaner is designed to have a range of features that help it achieve its objectives. This is achieved by learning from the built prototype and utilizing various sensors and appropriate PMDC Motors.

1.2 Functional Block Diagram

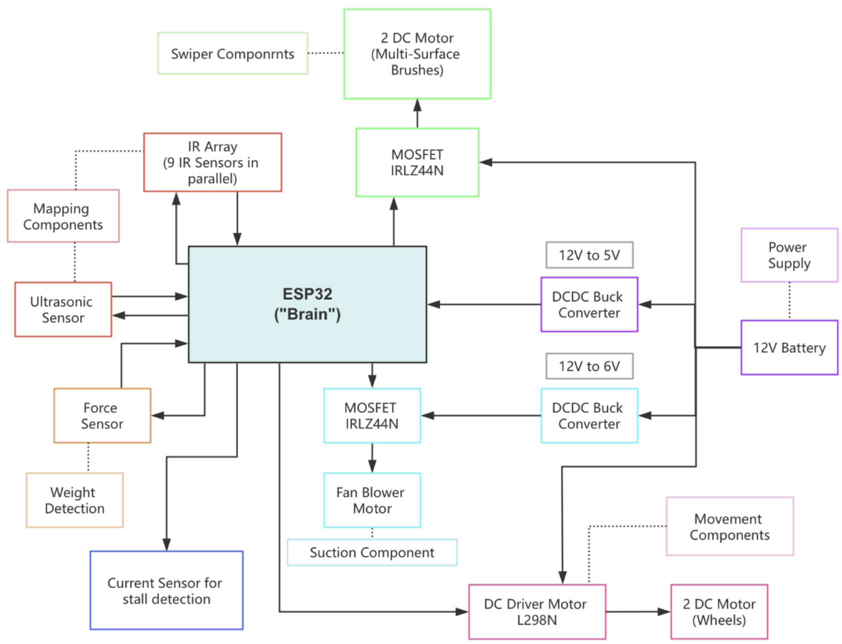


Figure 1.2.1 *Functional Block Diagram*

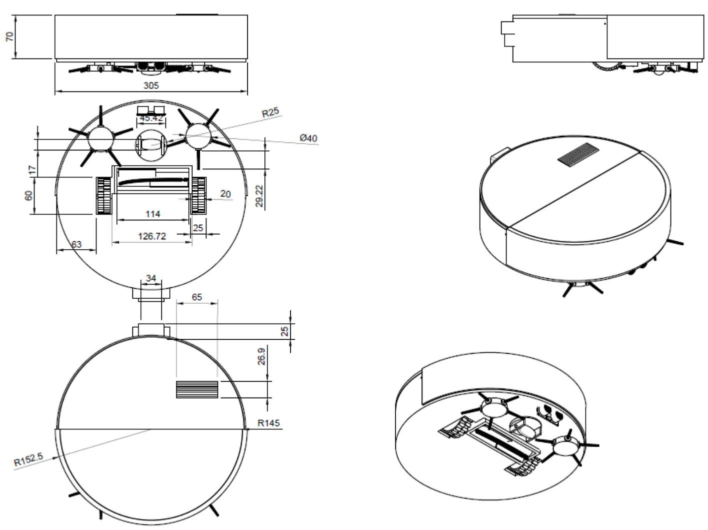
1.3 Brief Description of How the System Works

The robotic vacuum cleaner operates autonomously under the control of the ESP32, which coordinates all sensor inputs and motor outputs. The robotic vacuum uses ultrasonic and IR sensors for obstacle detection, a force sensor for dust collection weight, and IR sensors for charging alignment. Powered by a 12V battery and DC-DC converters, it cleans autonomously, operates on a schedule, and provides real-time feedback, notifying users when the dust container is full. Additionally, the robot is programmed to begin cleaning at scheduled times and provides real-time feedback.

Detailed design

2.1 Sketch showing the shape of the robot and component placement

Figure 2.1.1: *Proposed Design of Robot Vacuum*



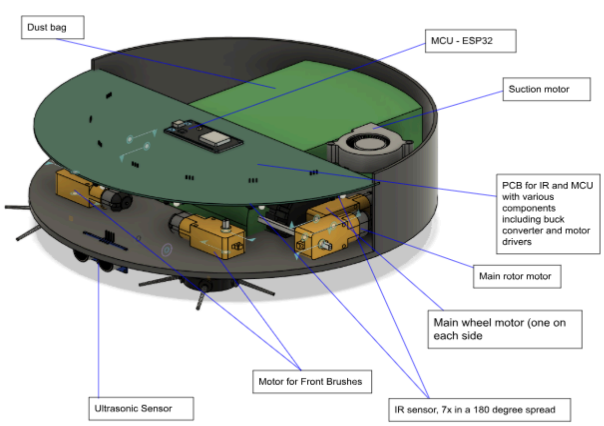


Figure 2.1.2[1]: Part 1 of Component Placement

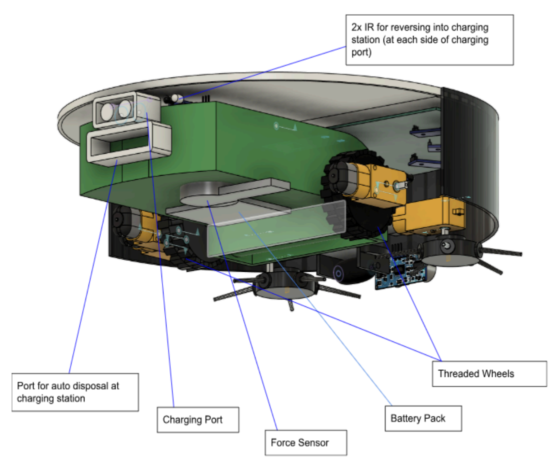


Figure 2.1.3*: Part 2 of Component Placement*

As shown in Figure 2.1.1, we have chosen a circular appearance design to prevent the robotic vacuum cleaner from causing damage to the surrounding furniture or items. Additionally, this structure enables the robot to turn flexibly and extricate itself from trouble in narrow spaces.

As shown in Figure 2.1.2, the robot is equipped with an ultrasonic sensor at the front, which is used to detect obstacles ahead and enable quick obstacle avoidance. Two front brushes are arranged below for cleaning edge dust, and their drive motor is installed above them to save space. Both the main wheel motor and the main rotor motor are positioned in the center of the robot, which helps maintain the overall balance of the center of gravity and reserves space for other components. A large-capacity dust bag is located at the tail of the robot to store the dust collected during the cleaning process. The suction motor is positioned adjacent to the dust bag, allowing for a direct connection and efficient collaboration between these two components. During cleaning, an ultrasonic sensor with a 7 IR sensor array, mounted in a 180° sweep at the front, continuously measures the distance to obstacles.

As shown in Figure 2.1.3, the port for auto disposal at the charging station and the charging port are designed in the connection area, maintaining the exact width to ensure that the robot can complete the connection and empty the dust bag operations during recharging. Two infrared sensors (IR) are installed on each side of the charging port to provide alignment guidance as the robot reverses into the charging station. The force sensor is installed beneath the dust bag, allowing for real-time detection of the dust's weight. The battery pack is located at the bottom of the dust bag, which not only conserves internal space within the machine body but also maintains the machine's center of gravity stability. The overall design features a circular black shell, which allows for convenient and straightforward rotation in confined spaces. The sweeper brushes and the main rotor are installed at the bottom to facilitate efficient cleaning of ground dust and debris. Additionally, the robot is equipped with a front-rotating wheel.

2.2 Calculations

Specification of our robotic vacuum cleaner:
Our estimate of the robot's mass, based on the rendered model, is approximately 5.5 kg.
Weight of robot = 5.5 × 9.8 = 53.9 N ≈ 54N
Extracting the dimensions from the detailed design,
Robot diameter: = 305mm = 0.305m
Robot radius = 0.305 / 2 = 0.1525m
Wheels radius = 30mm = 0.03m

Speed calculation:
The area we are required to clean is 1000 sq ft = 92.91 m^2
Assuming that the length of the room is 40 ft and the width of the room is 25 ft
So length = 40 ft = 12.2 m
Width = 25 ft = 7.6 m
According to the Narwal blog, the average time a vacuum robot needs to clean 250 sq ft is 30-45 minutes. Therefore, 1000 sq ft will require 120-180 minutes. We assume 120 minutes to be the time for our robot:
Robot diameter = 0.305m
Assuming the robot takes the shortest and most efficient cleaning route,
Distance required to cover = Area / Width of robot = 92.91 / 0.305 = 304.7 m
Speed required = Distance / Time = 304.7 / (120 x 60) = 0.04232 m/s
Min Speed = 0.04232 / 0.03 = 1.411 rad/s = 13.48 rpm

Torque calculation:
Assuming that the floor of the room is ceramic, the wheel material we used is rubber.

Weight of the robot = 5.5 x 9.81 = 54 N. From the diagram, the corresponding friction coefficient is 0.9.
Force:
F = Friction Coefficient x Weight = 0.9 x 5.5 x 9.81 = 48.56 N
Torque on the wheel:
T = F x r (radius of wheel) = 48.56 x 0.03 = 1.457 Nm
Torque required by each motor = 1.457 / 2 = 0.7285 Nm
Motor (Wheels):

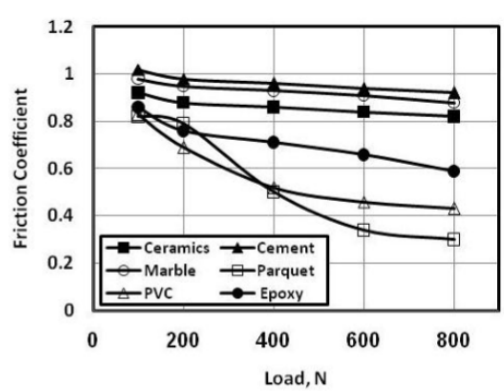


Fig. 7. Friction coefficient displayed by rubber sliding against dry flooring materials.

According to datasheet of FIT0492-A, Rated voltage = 12 V, Current rating = 0.68 A
Power = 12 x 0.68 x 2 = 16.32 W

IR Sensor:
According to the datasheet of the IR sensor we chose: Voltage = 3.3 V, Current = 0.02 A
Power Usage of 1 IR sensor = V x I = 3.3 x 0.02 = 0.066
Total Power usage for 9 IR sensor = 0.066 x 9 = 0.594 W
Ultrasonic Sensor:
From the datasheet: Working voltage = 3.3 ~ 5 V, Working current = 15 mA
Power Usage of 1 Ultrasonic Sensor = V x I = 3.3 x 0.015 = 0.0495 W
Force Sensor:
Power Usage of 1 Force Sensor = V x I = 3.3 x 0.004 = 0.0132 W
Motor (Spinning Brush):
Since the working voltage is 12V:
Power = (12 x 0.17) x 3 = 6.12 W
Motor (Suction, 6V 10000 RPM):
Using 12V to 6V buck converter,
Power = Vout × Iout = 6V × 1.5A = 9W
Current in = P / Vin = 9W / 12W = 0.75A

Total Power = 16.32 + 0.594 + 0.0495 + 0.0132 + 6.12 + 9 = 32.10 W
Assuming 80% system efficiency,
Power required = 32.1 W / 0.8 = 40.13 W
Energy required = 40.13 W x 2h = 80.25 Wh
Battery Capacity = 80.25 Wh / 12 V = 6.688 Ah
Total Current drawn (from every component) = 3.233A
Calculating total power and energy required, we have the following requirements for the battery.
(12V, 7000mAh, while having a safe discharge current >= 3.24A)

2.3 Bills of Materials

No.	Part #	Name	Qty	Unit Cost/$	Cost/$
1	DC Motor (Wheels)	FIT0492-A	2	18.63	37.26
2	Motor Driver	L298N	1	16.34	16.34
3	IR Sensor	LM393 + TCRT5000	9	0.44	3.920
4	Ultrasonic Sensor	HC-SR04-33	1	8.05	8.05
5	Force Sensor	FSR 402	1	13.80	13.80
6	Mosfet	IRLZ44N	2	1.23	2.46
7	Step-Down Buck Converter	LM2576HV	2	9.00	18.00
8	Motor (Spinning Brush)	JGB37-520	3	8.32	24.96
9	Motor (Vacuum Suction)	RM-ESMO-0FB	1	9.82	9.82
10	Rotating Fan	Unbranded	1	17.41	17.41

11	Battery	LI18650-2400-3S3P	1	27.08	27.08
12	Dustbag	Roborock	3	13.30	39.90
13	Wheels	Unbranded	2	3.37	6.74
14	Bristle Brush	Unbranded	1	6.76	6.76
15	Spinning Brush	Unbranded	2	1.66	3.32
16	Current Sensor	ACS712ELC	1	2.17	2.17
17	Logic board	ESP32	1	15.60	15.60
18	Diode	1N5819-T	2	0.52	1.04
19	100 Ohm Resistor	CF14JT1M00	2	$0.14000	0.28
20	218 Ohm Resistor	CF12JT180K	1	$0.14000	0.14
21	5k Ohm Resistor	RN65E5001BB14	1	$3.43000	3.43
22	1K Ohm Resistor	CF12JT1K00	2	$0.14000	0.28
23	10k Ohm Resistor	CF1/4CT52R103J	1	$0.14000	0.14
24	200 Ohm Resistor	WW3FTR200	1	$1.64000	1.64
Total Cost					**260.54**

2.4 Schematic drawing of the electrical and electronic system

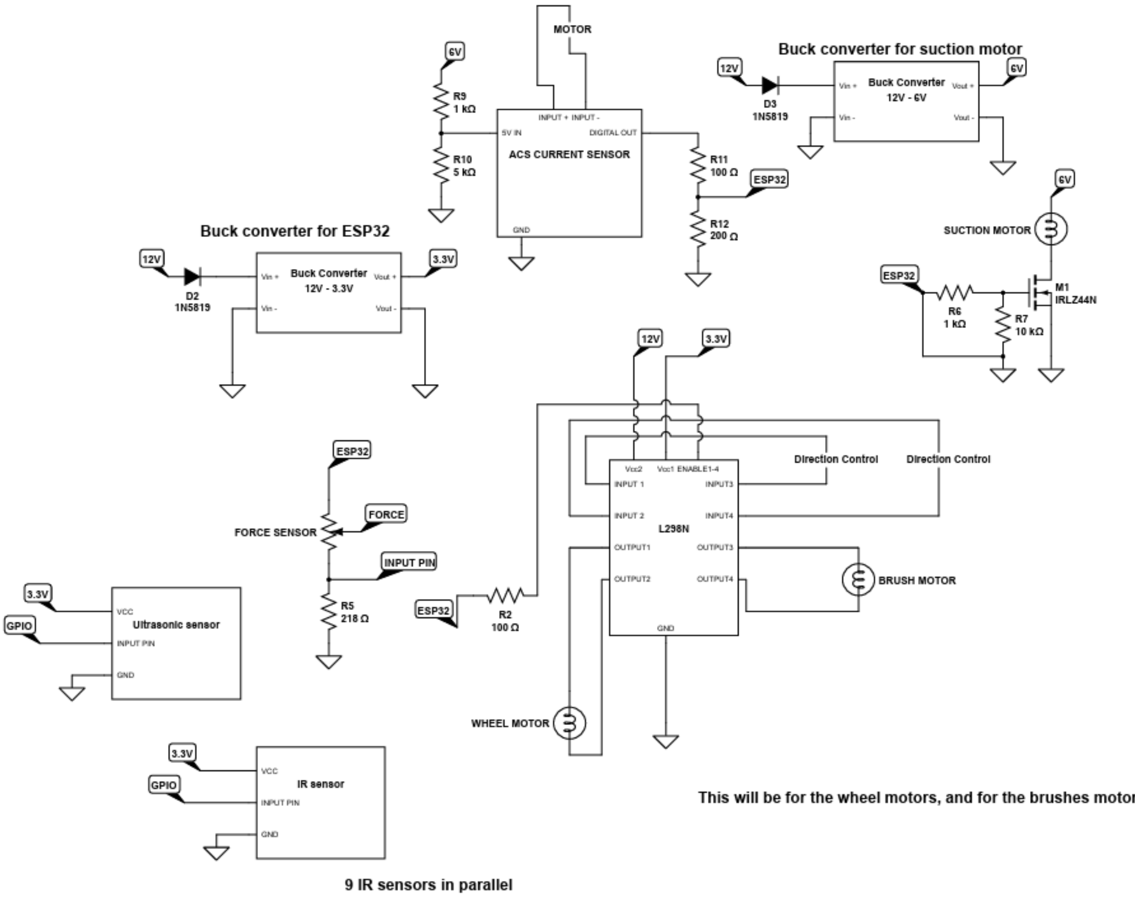


Figure 2.4.1: *Schematic Drawing*

2.5 Pseudocode

- Preprocessing:/
  - - Ask the user: "How big is your house? (in sq ft)"
  - - Ask user to take photo(s) of house layout via mobile app
  - - Use AI to generate 2D grid map of house (each cell = fixed floor area)
  - - Connect to WiFi and sync with app + home network
  - - Send the grid map to the robot
- Begin Cleaning:
  - - Start session timer
  - - Initialize robot's current grid position = (0, 0), which is also where the charging station is
  - - Mark current grid as CLEANING_IN_PROGRESS
- Main Cleaning Loop:
  - Navigate to the grid cell using odometry
  - - While in grid:
    - - Move forward

            - - If the ultrasonic sensor detects an object:
                - - Stop
                - - Mark the grid as OBSTACLE
                - - Turn left or right to move to the following grid
            - - If motor current > threshold:
                - - Stop
                - - Mark the grid as OBSTACLE
                - - Turn left or right to move to the following grid
            - - If force sensor > full_threshold:
                - - Sound buzzer
                - - Log: dust bag full
            - - Break cleaning loop → go to the dock
            - - Mark grid cell as CLEANED
- End of Cleaning:
    - - Generate report:Time cleaned + % of house cleaned + Dust bag status + where it did not clean (Obstacle positions)
    - - Sendthe report to the app
- Docking Sequence:
    - - Use Manhattan distance to return to the charging grid while avoiding obstacles
    - - Use the IR sensor to locate the dock signal in the grid
    - - Use ultrasonic to approach the dock while the IR is still detected
    - - Stop when close enough to charge

Conclusion

In this project, we have designed an autonomous robotic vacuum cleaner capable of cleaning a 1,000 sq ft area on a single charge, navigating obstacles, monitoring dust bag capacity, and returning to a charging station. Using an ESP32, an IR sensor array, ultrasonic ranging, force sensing, and PMDC motors, our system meets the key objectives of reliable navigation, efficient debris collection, user alerts, and scheduled operation via Wi-Fi. Our calculations show that two 12 V wheel motors, paired with a 7 Ah battery pack, can sustain the required 0.042 m/s traversal speed for two hours of cleaning with adequate torque to overcome floor friction. The bill of materials and schematic provide a cost-effective, modular build, totalling approximately $260, while the pseudocode outlines a grid-based cleaning and docking algorithm.

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