Re-Sizeable Autonomous Cleaning Robot

Submitted in partial fulfilment of the requirements for the degree of

Bachelor of Technology

in

Mechanical Engineering

By

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(Deemed to be University under section 3 of UGC Act, 1956)

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Declaration

We hereby declare that the thesis entitled "Re-Sizeable Autonomous Cleaning Robot" submitted by Kahaan Patel (18BME0691), Sahil Chaudhary (18BME0668) and Mehul Chaurasia (18BME0640), for the award of the degree of Bachelor of Technology in Mechanical Engineering to VIT is a record of bonafide work carried out by me under the supervision of Dr. Chinmaya Sahu.

We further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university.

Place: Vellore

Date: 28th March 2022

Signature of the Candidates

Certificate

This is to certify that the thesis entitled "Re-Sizeable Autonomous Cleaning Robot" submitted by Kahaan Patel (18BME0691), Sahil Chaudhary (18BME0668) and Mehul Chaurasia (18BME0640), School of Mechanical Engineering, VIT University, for the award of the degree of Bachelor of Technology in Mechanical Engineering, is a record of bonafide work carried out by them under my supervision during the period, 15.01.2022 to 20.04.2022, as per the VIT code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute or any other institute or university. The thesis fulfils the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

Place: Vellore

Date: 28th March 2022

Signature of the Guide

Internal Examiner

External Examiner

Head of the Department

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Abstract:

Cleaning robots have advanced significantly in recent years, owing to increased market presence and the demand for improved cleaning performance. However, due to geometric restrictions of the platforms in relation to the cleaning stage, as well as furniture and architecture, most robots have difficulty covering the whole cleaning area. The aim is to use the on-board sensors which will mainly be a combination of SLAM (Simultaneous Localization and Mapping) integrated using LIDAR and camera to detect obstacles and change the robot configuration accordingly and to navigate forward and backward and even sideways with the help of mecanum wheels. The plan is to use a ball screw actuation mechanism to change the length of the robot according to what it maps about the local terrain using the sensors. For this purpose, a precise CAD model will be designed with the decided parameters so as to bring down the cost of making the cleaning robot to the bare minimum while also optimizing its cleaning efficiency at the same time.

Introduction:

Cleaning has always been an important and necessary aspect of human lives, and it has developed and changed over time. The need for completely automated floor cleaning robots has surged as a result of today's hectic lifestyle.

Automated floor cleaning robots are commonly employed in smart homes, residential, and office spaces to clean the floors.

According to a world market study, there is a strong demand for the application of these robots in domestic settings with fully automated functionalities and the least amount of human assistance, and while these robots still account for a small percentage of the global vacuum cleaner market, their recognition and implementation is growing at a rapid rate.

The robots are small and execute the cleaning operation without the need for human participation. These robots use motion planning algorithms to cover a large area while cleaning, such as spiral motion, backtracking spiral motion, boustrophedon motion (back and forth), and basic zig-zag motion patterns.

Even though fixed-configuration robots have sufficient path planning and motion skills, they may require more time and energy to complete the complicated task effectively than their changeable counterparts. As a result, building a re-sizeable robot that can increase the swept area in open spaces can reduce the time taken to clean. This project focuses on the design and development of the same.

Literature Review:

Prassler et al. demonstrated almost how all commercial home cleaning robots are equipped with vacuum cleaners as their primary means of cleaning. Pool cleaning robots have also been developed. Some robots also have wet scrubbers to clean the floor (non-textile floor coverings), and some also clean carpets. Some industrial robots have sweepers along with vacuum cleaners. Duct cleaning robots with rotating brushes have also been developed. Sensors that are usually employed include Ultrasonic, LIDAR, IR, Cameras and Contact. Robots are navigated using dead-reckoning, manually using a joystick, or even using magnetic markers to guide the way. Safety features include front bumpers that absorb impact shock. Robot road sweepers have also been developed for cleaning large open spaces. [1]

Endres et al. developed robots for cleaning purposes in the supermarkets. There are some special features in these robots, they consist of a retractable wing which is inserted in the right part of the robot. The use of this retractable wing allows the robot to get close to the objects and precisely cleans the floor without colliding with the obstacles. Also, the size of this wing can be adjusted according to the requirement it can be extended or reduced as needed. The main features of this robot were: To identify the obstacles properly for cleaning the environment, executing the plan properly, no need to install any additional part to localize the robot, a systematic skill to move around the obstacles for least energy consumption. [2]

Kushal et al. have worked on a cleaning robot ATMEGA 2560 which worked with two modes: automatic and manual. The hardware used were Arduino Mega 2560, Ultrasonic Sensor, DC Generated Motor, Vacuum Motor, L298n Dual H-Bridge Motor Driver, VL53LOX Laser TOF Sensor and Servo Motor. Since the robot has two modes, one of them is manual mode which is selected when the robot switch is high and allows the users to reach places which are not automatically detected by the robot. And for the autonomous mode there is an algorithm which is followed by the robot with path planning. There is also a water sprayer attached so that the robot can also be used for the moping purposes as for the convenience of the user. [3]

Sewan Kim et al. demonstrated the Roboking system integration in an autonomous cleaning robot. The purpose of this robot was the protection of the indoor cleaning environment while the robot is working. There are many different sensors and the functions which are integrated in this system. The robot uses a digital signal processor from Texas Instruments (320LF 2406A). It works on 40MHz frequency with 24 sensors performing the operations together gathering different signals from internal subsystems. Also, there are 14 ultrasonic sensors which are installed in the robot, where nine of them were used in the lower part to find the obstacles. And the others were used on the upper part so that the robot does not collide with the tall obstacles. For the Roboking mechanism, there are cliff detecting sensors which determine the upliftment of the robot and prevent the robot from falling down. [4]

Liu et al. developed a system that did not rely on mapping and global self-localization. It consists of three layers. The lowest layer contains the sensors and hardware, which include ultrasonic (13 pairs, 7 for the front and the rest for the sides), IR, encoders, DC motors, vacuum etc. The second layer is responsible for the behaviour of the robot, which include point turning, line following, wall following, side shifting, and obstacle rounding. The third layer is responsible for carrying out tasks, like environment learning, cleaning and homing. [5]

Mahmud Hasan et al. demonstrated the use of bumper contact sensors and cliff IR sensors. The path planning algorithms include Random walk, spiral, 'S'-shaped path and wall follow. These four algorithms are cycled between until the entire area is covered. The motor specification is 2Amp/6VDC, 5500 rpm with 70:1 gearbox for the driving wheels. The side brush controlling motor specification is 0.5Amp/6VDC with a 30:1 gearbox. The vacuum motor is 5Amp/6VDC with 8000rpm (Cyclonic type dry vacuum is used). The battery used is 6V/4.5Ah lead-acid. The robot can operate for an hour. The battery takes 5-6 hours to charge. [6]

Joon et al. developed a combination of Lidar and camera. A manipulator arm containing the vacuum was attached to the mobile robot. The collector box has a volume of 378 cubic cm (10 cm × 6 cm × 6.3 cm). [7]

Shakhawat Hossen et al. discussed how LIDAR and GPS have been used for mapping and localization. IR proximity sensors and ultrasonic sensors were used for object detection. [8]

Gerstmayr-Hillen et al. discussed how an omnidirectional camera was used to generate panoramic images of the environment in order to map it, and hence guide and navigate the robot to cover a rectangular segment of the robot's workspace. The omnidirectional camera is used to simultaneously localize the robot and also map the environment. Hence, the camera carries out local visual homing and provides the data to generate a dense topological map. The robot is guided along parallel paths by controlling its distance from the previous lane. The distance is estimated using images from the camera and the robot's odometry. Only the robot's distance from the previous lane and its orientation are calculated. [9]

Karur et al. discussed various path planning algorithms. Dijkstra and A* algorithms are used for static environments, whereas D*RRT (Rapidly-Exploring Random Trees), Genetic, Ant Colony and Firefly algorithms are used for Dynamic environments. [10]

Dakulovic et al. demonstrated complete coverage of D* algorithm for path planning, using a combination of D* and PT algorithms. [11]

Lamini et al. demonstrated how GA (Genetic Algorithm) with improved crossover operators and fitness functions were employed to find optimal solutions. [12]

Amine Yakoubi et al. demonstrated that GA was used for path planning. Each gene represents the robot position and the chromosomes represent the mini-path. [13]

Liu et al. developed an algorithm for complete coverage path planning, which combines random path planning and local complete coverage path planning. Random path planning is very flexible for unstructured environments, but is inefficient. On the other hand, local complete coverage path planning generates a comb-like path to cover a relatively small area with high efficiency, but fails to do so in a larger area in an unstructured and dynamic environment. The proposed technique combined the benefits of both. 11 pairs of ultrasonic sensors were used, 7 for the front and the rest for the sides. [14]

Hofner et al. demonstrated path planning of a rectangular non-holonomic robot. Two changing maneuvers were used to navigate the robot – U-Turn and Side-Shift. Based on the parameters of the robot and the environment, the path planning algorithm will choose the most appropriate path planning template such that the entire floor area is covered efficiently. Localization was done using ultrasonic sensors and dead-reckoning. Subgoals were determined in the vicinity of various pre-planned landmarks. Vehicle guidance was done by finding the specified start location and compensation of path errors. [15]

Ramalingam et al. developed an algorithm for detecting and classifying debris as solid and liquid spillage using CNN and SVM was developed. This helped the robot to avoid hard to clean debris, as robots are mostly unable to clean such debris and hence end up spreading them on the floor rather than cleaning it, thus also reducing their efficiency. [16]

Schmidt et al. developed an algorithm that has been developed to memorize uncleaned areas that couldn't be cleaned in the first sweep because of a temporary obstacle, and then come back to clean it after the remaining area has been cleaned. [17]

Parween et al. developed a self-reconfigurable robot called hTrihex has. It enables the robot to cover spaces that are generally missed or inaccessible by the usual circular shaped cleaning robots (like corners). This robot can configure itself into three different configurations based on the requirements, namely – Straight, Chevron and Closed. The sensors used onboard are encoders, LIDAR and IMU, along with a PID controller for implementing a closed-loop system. A differential drive has been implemented to steer the robot and hence control the heading. [18]

Parween et al. developed another similar self-reconfigurable robot is the hTetrakis. It consists of four equilateral triangles, and can change between three configurations namely – "I", "A", and "U" shapes. These configurations enable the robot to access convex and narrow corners that are generally inaccessible by the common circular shaped cleaning robots. [19]

Forlizzi et al. demonstrated that mecanum wheels have their omnidirectional property that allow them to have excellent manoeuvrability and ability to move in a congested space. Congested spaces usually mean environments with static or dynamic obstacles or narrow areas respectively. Due to the Mecanum wheel's high manoeuvrability, it is ideal for outdoor applications like transportation purposes in warehouses, mining activities and even for military activities and indoor applications like autonomous robot cleaning that is the objective of this Capstone project. [20]

Laurena et al. developed and demonstrated control mechanism for actuating ball screw linear actuator. A ball screw linear actuator converts rotatory motion to linear motion. It has low friction and can withstand thrust loads. The programming and control system for the linear actuator was developed. [21]

Bhowmik et al. developed an algorithm for navigation of a cleaning robot by modifying the Dijkstra algorithm. A provision for backtracking and hill climbing were incorporated. This improved the performance of the Dijkstra algorithm. [22]

Gaps in the Literature:

After the exhaustive literature review it has been concluded that,

1. According to the literature review conducted, all the cleaning robots including the commercially available ones, are fixed in size and configuration.
2. A handful of self-reconfigurable robots have been developed. The objective of these robots is to cover hard-to-reach places, that conventional fixed configuration robots cannot.
3. Hence, the aim is to develop a re-sizeable robot that can increase its length to cover more area in a single sweep, and can also reduce its size to reach inaccessible areas.

Problem Definition:

Cleaning robots are available in a variety of sizes and can clean a specific area in a single sweep. However, the cleaning efficiency and effectiveness can be improved. In open places with little impediment, such as broad halls and living rooms, cleaning can be done quickly by sweeping a larger area in a single sweep. To address this problem, a re-sizeable cleaning robot is being developed that can extend its length, allowing it to cover a larger area in a single sweep, and can also reduce its size to reach inaccessible areas.

Objectives:

1. To design a system that can change the length of the robot depending on the need and area that is currently being cleaned.
2. To integrate an actuation mechanism for changing the length.
3. To integrate SLAM using LIDAR.
4. To integrate object detection using camera and/or ultrasonic sensors.
5. To conduct a Simulation study.

Methodology:

The theoretical design of the robot, as well as the basic components needed, have been finalised after extensive study and detecting gaps in the literature review, as well as recognising scope for improvement. The CAD model has been developed, based on the mathematical calculations and finalised components. The on-board sensors include LIDAR and camera to detect obstacles and change the robot configuration accordingly. The following steps include programming the robot's many functions like the ability to change its length according to the environment, and conducting simulations like controlling the size of the robot and the ability of the robot to manoeuvre with the help of Mecanum wheels. The primary components that have been used are:

1. <u>LIDAR</u>– LIDAR (Light Detection and Ranging) is a remote sensing technique that measures ranges (varying distances) to the obstacle using light in the form of a pulsed laser.

The aim is to use RPLIDAR A1 which integrates the concept of SLAM (Simultaneous Localization and Mapping). RPLIDAR A1 is a laser triangulation range system that employs Slamtec's high-speed vision acquisition and processing hardware. The technology takes distance measurements at a rate of around 8000 times per second. RPLIDAR A1's core rotates clockwise to perform 360-degree omnidirectional laser range scanning for its surrounding surroundings and then build an outline map.

2. Mecanum Wheels – Mecanum wheels have their omnidirectional property that allow them to have excellent manoeuvrability and ability to move in a congested space. Congested spaces usually mean environments with static or dynamic obstacles, or with narrow areas.

   The aim is to use a set of bush type aluminium Mecanum wheels with the following specifications:

   i) Diameter: 60 x 31 mm (Diameter x Width)
   ii) Body Material: Aluminium Alloy
   iii) Roller Material: Hard Rubber
   iv) Length of Roller: 30 mm
   v) Net Weight: 93 gm (Each)
   vi) Load Capacity: 3Kg/Wheel

3. Camera – The aim is to use a camera sensor for object detection so as to facilitate the cleaning robot to make its own autonomous decision. The objective is to use the Raspberry PI 5MP Camera Board Module. It will also enable a live video feed to be transmitted to any device via Wi-Fi or Bluetooth.

4. Raspberry Pi – The aim is to use Raspberry Pi 4 microprocessor as it is easier to integrate it with the SLAM based RPLIDAR A1 so as to facilitate smoother mapping of the terrain. Raspberry Pi 4 will be used specifically due to its high-performance 64-bit quad-core processor, 4 GB of RAM and dual display support with resolutions up to 4K via a pair of micro-HDMI ports.

5. Battery Pack – The aim is to use two 5000mAh 22.2V battery packs with maximum discharge current and maximum charging current as 15000 mA and 5000 mA respectively. Instead of using one big 10000mAh battery, the plan is to use two 5000mAh battery connected in parallel as the voltage remains constant and increase the duration for which it could power equipment. It’s important to note that when charging batteries that are connected in parallel, the increased amp-hour capacity may require a longer charge time.

6. IMU – The aim is to use MPU9250 9-Axis Attitude Gyro Accelerator Magnetometer Sensor Module with a power supply of 3.3-5 V (DC) and dimensions 22 X 17 mm with 9 DOF modules.

7. Wheel Motor – The aim is to use a compact DC Motor with High Power Density and high efficiency. The following are its characteristics:

i) Input Voltage of 12 V (DC)
ii) No Load Speed = 9900 rpm
iii) Nominal Speed = 8050 rpm
iv) Maximum Output power = 6.64 W
v) Life (Typical) = 1000 hrs

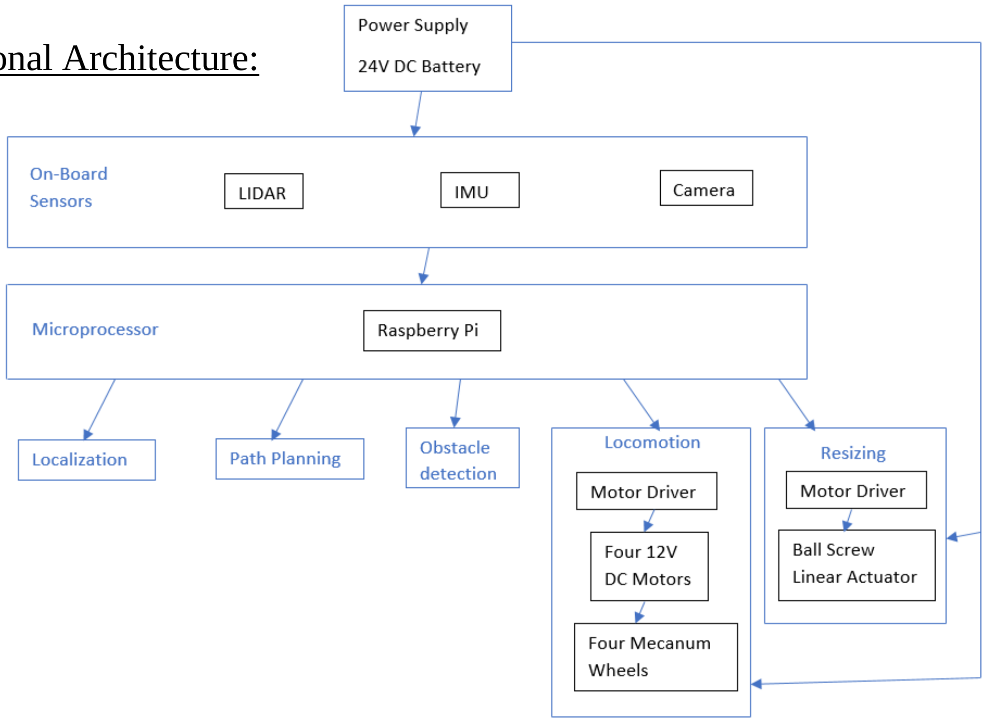
8. Ball Screw Actuator – Ball screws are mechanical linear actuators made up of a screw shaft and a nut with a ball that rolls between helical grooves that correspond. Ball screws' main purpose is to transform rotational motion into linear motion. Ball nuts are used to transmit forces to a static or dynamic load with excellent precision, reproducibility, and accuracy. The rolling balls in the helical groove of ball screws are a unique feature that eliminates mechanical contact inside the screw assembly and replaces sliding friction with rolling friction. This technique reduces friction greatly, resulting in a very efficient power conversion. Screw efficiency is determined by their capacity to convert power used to exert rotating force into linear distance travelled.

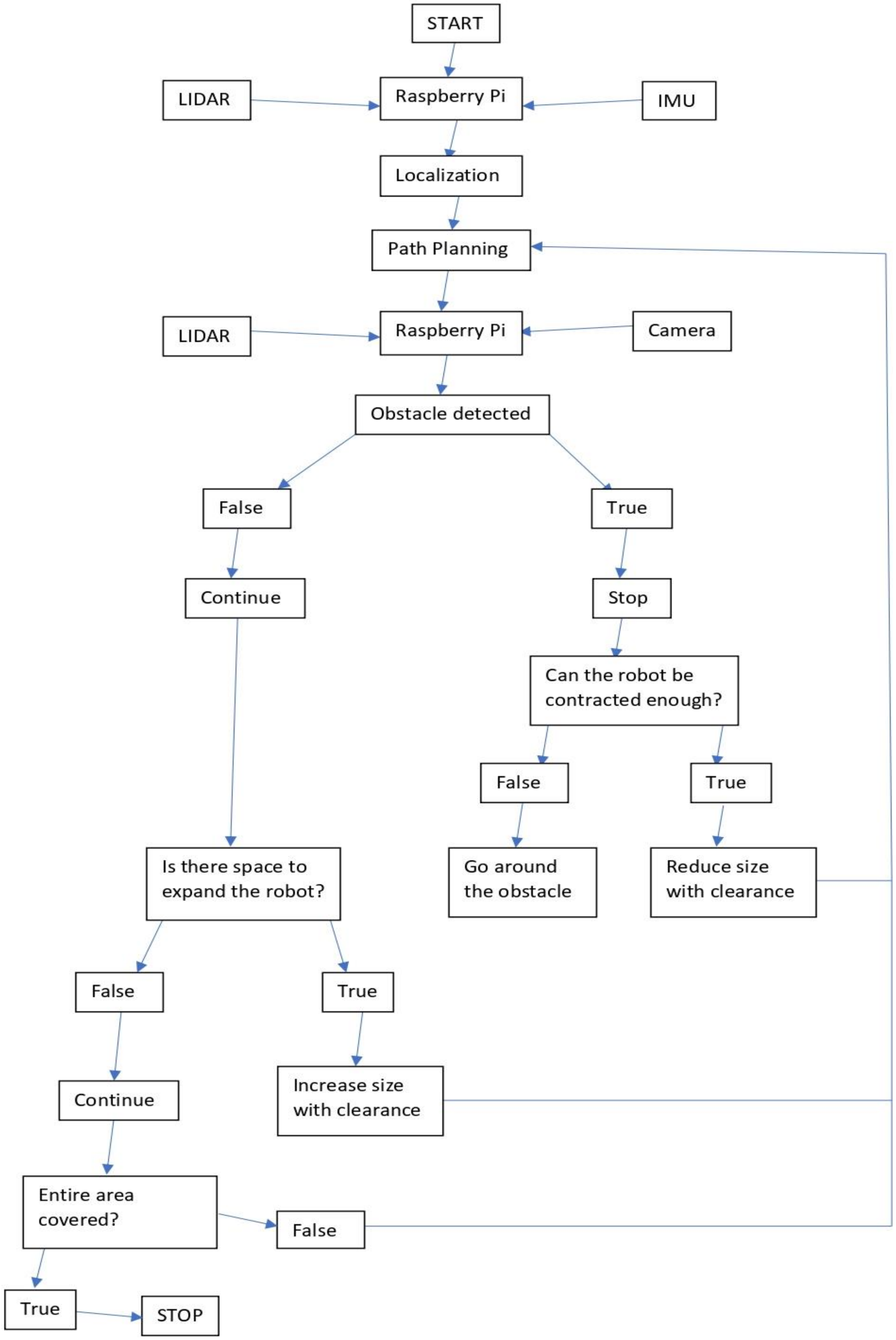
   The aim is to use ball screw linear actuators to control the size of the robot.

Work Carried Out:

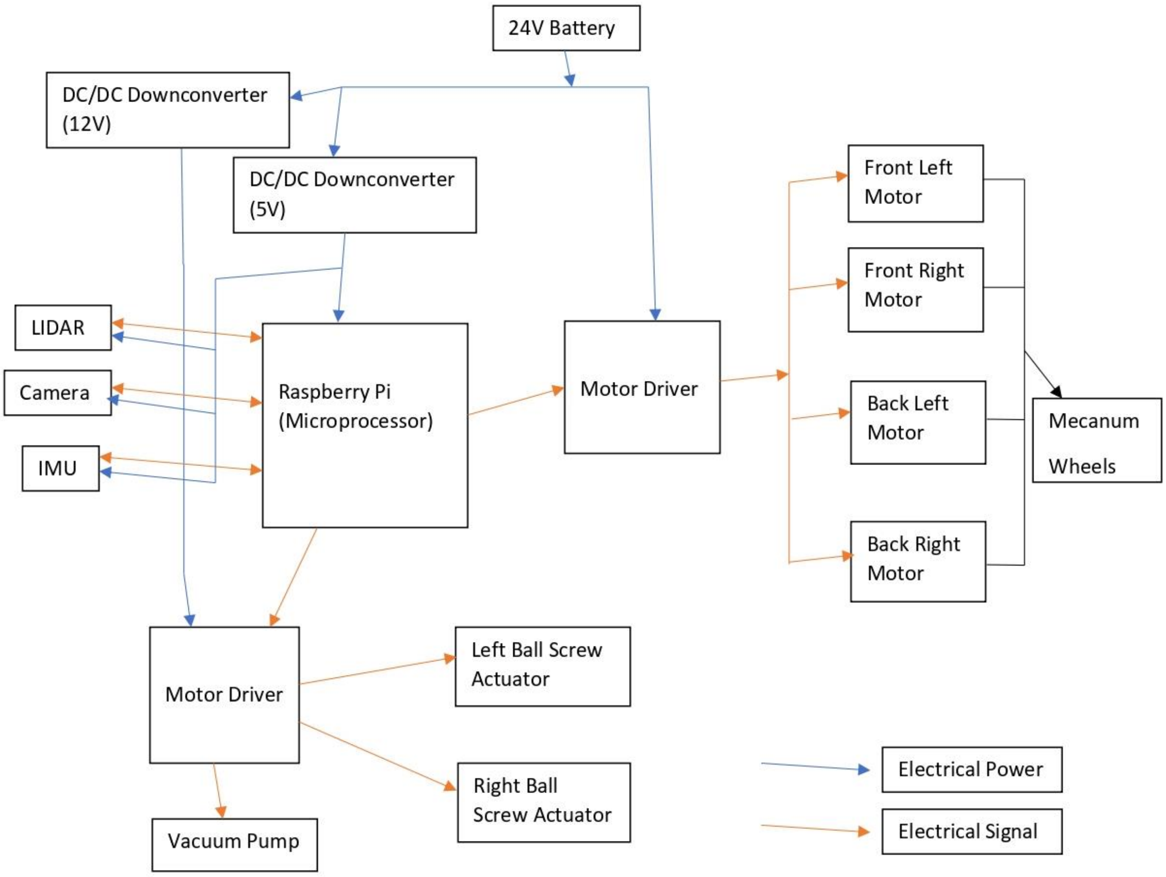
1. Literature review has been completed.
2. Problem statement defined.
3. The primary components required to make the robot have been finalised.
4. The conceptual design of the robot, including the mechanism to change its size, has been developed.
5. The Functional Architecture has been developed.
6. Mathematical analysis required for the research has been conducted.
7. The components have been finalized.
8. A detailed CAD Model has been developed.
9. Basic Simulation study has been initiated.

Functional Architecture:




START
LIDAR
Raspberry Pi
IMU
Localization
Path Planning
LIDAR
Raspberry Pi
Camera
Obstacle detected
False
True
Continue
Stop
Can the robot be contracted enough?
False
True
Go around the obstacle
Reduce size with clearance
Is there space to expand the robot?
False
True
Continue
Increase size with clearance
Entire area covered?
False
True
STOP

Circuit Diagram:



Design Calculations:

Wheel Motor Torque Calculation for the 4 Mecanum Wheels:

Mass of Cleaning Robot = 9 kg
Radius of wheel = 0.03 m

$\tau = \mu * m * g * R$

1. Case 1 (Wooden Floor)

   Coefficient of Friction between hard rubber and wooden floor = 0.7
   Total Torque = 9*9.81*0.7*0.03 = 1.85409 Nm
   Individual Torque of each motor = 1.85409/4 = 0.4635225 Nm

2. Case 2 (Ceramic)

   Coefficient of Friction between hard rubber and ceramic tile = 0.32
   Total Torque = 9*9.81*0.32*0.03 = 0.847584 Nm

Individual Torque of each motor = 0.847584/4 = 0.211896 Nm

3. <u>Case 3 (Marble)</u>

   Coefficient of Friction between hard rubber and marble tile = 0.25
   Total Torque = 9*9.81*0.25*0.03 = 0.662175 Nm
   Individual Torque of each motor = 0.662175/4 = 0.16554375 Nm

4. <u>Case 4 (Smooth Concrete)</u>

   Coefficient of Friction between hard rubber and smooth concrete surface = 0.38
   Total Torque = 9*9.81*0.38*0.03 = 1.006506 Nm
   Individual Torque of each motor = 1.006506/4 = 0.2516265 Nm

5. <u>Case 5 (Rough Concrete)</u>

   Coefficient of Friction between hard rubber and rough concrete surface = 0.62
   Total Torque = 9*9.81*0.62*0.03 = 1.642194 Nm
   Individual Torque of each motor = 1.642194/4 = 0.4105485 Nm

Vacuum System Calculations:

Taking D = 3 cm (1.1811 in), and L = 5 cm (1.9685 in)

Speed of pump, S_p = 49.3 CFM = 23.267 L/s

Now,

Conductance of the system,

$$C = \frac{78 * D^3}{L}$$

$$C = \frac{78 * 1.1811^3}{1.9685} = 65.2858\ L/s$$

$$\therefore C = 133.3327\ CFM$$

Therefore,

Effective pump speed, S

$$\frac{1}{S} = \frac{1}{S_P} + \frac{1}{C}$$

$$\frac{1}{S} = \frac{1}{23.267} + \frac{1}{133.3327}$$

$$\therefore \mathrm{S} = 19.81\ \mathrm{CFM}$$

Now,

Velocity at orifice,

When robot is fully extended: A = 50 x 0.5 cm^2 = 0.0269098 ft^2

$$Q = Av$$

$$\therefore v = \frac{19.81}{0.0269098} = 736.163\ ft/min$$

$$v = \ 3.74\ \mathrm{m/s}$$

When robot is at minimum extension: A = 30 x 0.5 cm^2 = 0.01614 ft^2

$$Q = Av$$

$$\therefore v = \frac{19.81}{0.01614} = 1227.385\ ft/min$$

$$v = 6.235\ \mathrm{m/s}$$

Battery Life Calculations:

Essential Components:

1. Units of Motors = 15*4 = 60 W
2. Vacuum Pump = 40 W
3. RPLIDAR A1 = 0.5 W
4. Camera = 7.5 W
5. Raspberry Pi 4 Model B = 25 W

Total Power Consumption by the essential components = 133 W

Rounded off to 135 W for ease of battery life calculations.

Battery type chosen is Lithium-ion

Battery Life = 240 Watt-Hour/135 W = 1.78 hours = 106.8 mins = 107 mins (Rounded off)

Component Table:

Component	Qty	Specs/Model Name	Dimensions	Weight	Price (Rs.)
LIDAR	1	RPLIDAR A1	98.5 x 70 x 60 mm	170 g	8,549

Mecanum Wheels	4	45° in Tank Drive configuration, Load 3Kg/wheel	60 x 31 mm (Diameter x Width)	93 g (per wheel)	5,549
Vacuum Pump	1	Nidec G10D	97 x 94 x 33 mm	180 g	8,538
Dust box	1	With HEPA Filter	600 ml	87 g	150
Battery pack	2	Orange 18650 Li-ion 5000mAh-6s-22.2v-3c 6S2P	160 x 100 x 50 mm (for 1)	770 g (x2)	3,299 (x2)
Wheel Motor	4	Johnson Geared Motor (Grade B) 12 V DC	Ø 27 X 64 mm (for 1)	164 g (x4)	384 (x4)
Motor Driver	2	L298N 2A Based Motor Driver Module	44 x 44 x 28 mm	25 g (x2)	129 (x2)
Raspberry Pi	1	Raspberry Pi 4 Model B 4GB	85.6mm x 56.5mm	52 g	5,149
Camera	1	Raspberry PI 5MP Camera Board Module	4 x 3 x 2 cm	10 g	389
IMU		MPU9250 9-Axis Attitude Gyro Accelerator Magnetometer Sensor Module	25 x 15 x 3.5 mm	5 g	749
Ball Screw Actuator	2	Linear Actuator Stroke Length 100MM,7mm/S,1500N,12V	210 x 74 x 36 mm	889 g (x2)	3900 (x2)
DC/DC Converter	1	24V/12V to 5V 5A Power Module DC-DC XY-3606 Power Converter	63 x 27 x10 mm	22 g	289
DC/DC Converter	1	A2412S-1WR2 Mornsun 24V to ±12V DC-DC Converter 1W Power Supply Module - Ultra Compact SIP Package	19.5 x 6 x 9.3 mm	2.4 g	395

Component Images:

1. LIDAR Scanner:

[Figure 1]

RPLIDAR A1 has been chosen as it has been specifically designed for indoor robotic SLAM applications, and has been designed for the Raspberry Pi 4 Model B microprocessor, which is the microprocessor used in the robot.

2. Mecanum Wheel:

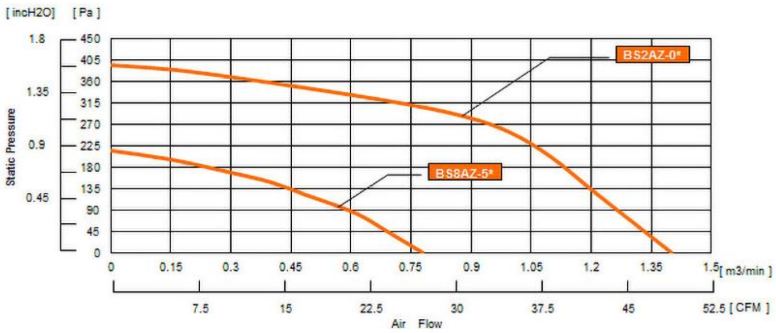
   i) Φ60 mm
   ii) Load Capacity: 3Kg/Wheel
   iii) Body Material: Al Alloy
   iv) Length of Roller: 30 mm

[Figure 2]

Mecanum wheels with 45° roller orientation have been chosen for the added manoeuvrability and degrees of freedom they provide, such as strafing and turning on the spot.

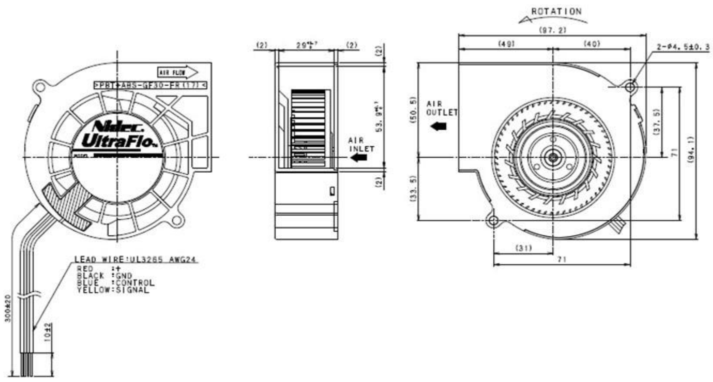
3. Vacuum Pump:

   i) Model: Nidec G10D
   ii) Rated speed: 5700 RPM
   iii) Max. Airflow: 49.3 CFM
   iv) Max. Static Pressure: 395 Pa
   v) Rated Voltage: 12 V
   vi) Rated Input: 38.4 W



[Figure 3]

[Figure 4]



[Figure 5]

The vacuum pump has been chosen on the basis of space available inside the robot, and the maximum discharge that it can provide, measured in CFM (Cubic Feet per Minute).

4. <u>Battery Pack:</u>

   i) Model: Orange 18650 Li-ion
   ii) Nominal Voltage: 22.2 V
   iii) Max. Charging Voltage: 25.2 V
   iv) Nominal Capacity: 5000 mAh
   v) Max. Discharge Current: 15 A

[Figure 6]

A battery pack consisting of two 24V 5000 mAh batteries connected in parallel has been chosen for its excellent battery backup. Such a large battery pack is feasible because there is sufficient space inside the robot.

5. <u>Wheel Motor:</u>

   i) Johnson Geared Motor (Grade B)
   ii) Base Motor RPM: 18000
   iii) 500 RPM
   iv) Rated Torque: 0.1 Nm
   v) Stall Torque: 0.48 Nm
   vi) Nominal Voltage: 12 V
   vii) Operating Range: 6 – 18 V

[Figure 7]

A geared DC motor with relatively high torque to meet the torque requirement as per the mathematical analysis has been chosen. Since it is a cleaning robot, high robot velocity is not a priority, hence 500 RPM is sufficient.

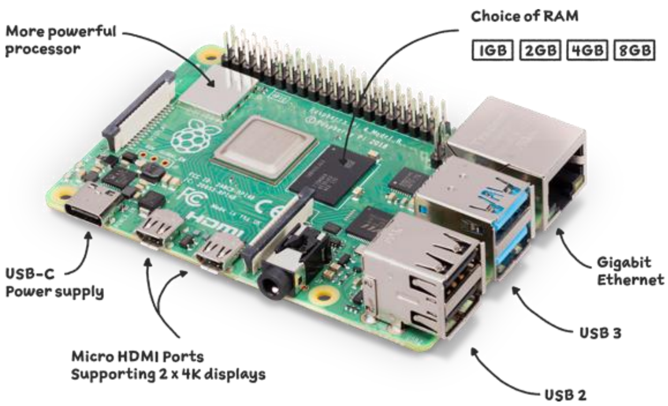
6. <u>Motor Driver:</u>

   i) Double H bridge Drive Chip: L298N 2A
   ii) Operating Voltage (VDC): 5~35
   iii) Peak Current (A): 2
   iv) Continuous Current (A): 0-36mA
   v) No. of Channels: 2
   vi) Can control up to 4 DC Motors

[Figure 8]

L298N Motor driver has been chosen since it is a very popular choice for robotics projects, and it also meets the design requirements of the robot. It can control up to 4 DC motors, has an inbuilt 5V regulator, and is very cost effective. The robot will use two of these motor drivers – one for the four wheel motors, and one for the two ball screw actuator motors and the vacuum pump motor.

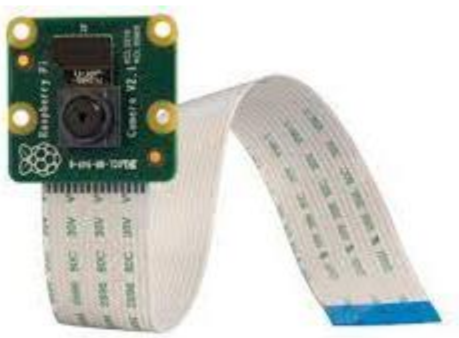
7. Raspberry Pi 4:



[Figure 9]

Raspberry Pi 4 Model B 4GB has been chosen because of the complexity of the robot and its various subsystems. A powerful microprocessor is needed to coordinate and execute all the various subsystems in real time.

8. Camera:

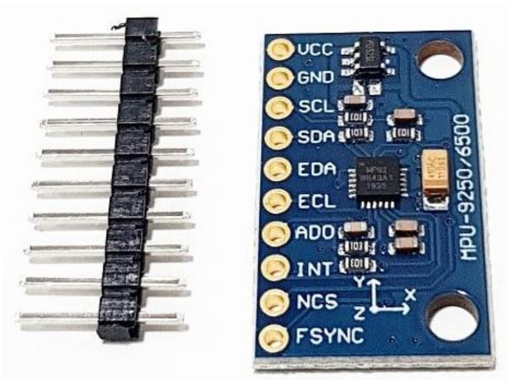


i) Model: Raspberry Pi 4 Model B camera module
ii) Resolution: 5 MP
iii) Supported Video Formats: 1080p @ 30fps, 720p @ 60fps and 640x480p 60/90 video
iv) Fully compatible with Raspberry Pi 3/4

[Figure 10]

A Raspberry Pi 4 Model B camera module has been chosen because of its
low cost, and compatibility and ease of integration with the Raspberry Pi 4 Model B microprocessor. A camera module is needed for object detection and to transmit a live video feed via Bluetooth/Wi-Fi.

9. IMU:



i) Model: MPU9250
ii) Accelerometer, Gyroscope & Magnetometer
iii) 9 DOF Modules
iv) Power Supply: DC3.3V-5V
v) Chip: MPU9250
vi) Gyro range: ± 250 500 1000 2000 °/s
vii) Acceleration range: ± 2 ± 4 ± 8 ± 16g
viii) Magnetic field range: ± 4800uT

[Figure 11]

An IMU module has been chosen to fulfil the localization needs of the robot. It has 9DOF and is cost effective.

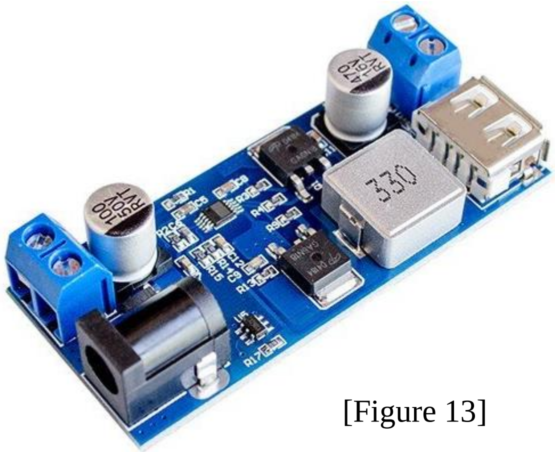
10. Ball Screw Actuator:

i) Stroke Length: 100 mm
ii) 7 mm/s
iii) Permanent magnet DC motor drive: Voltage 12VDC
iv) Self-Locking Force: 1500N
v) Aluminium frame and extension tube
vi) Long life: A service life of more than 50000 times

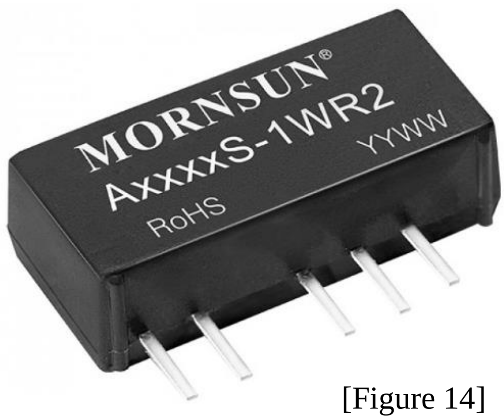
[Figure 12]

Ball screw linear actuators have been chosen to facilitate the extension and retraction of the robot. The stroke length perfectly matches the project needs, frictional losses are minimal, and controlling it is relatively easy because of DC motors.

11. DC/DC Converters:



[Figure 13]



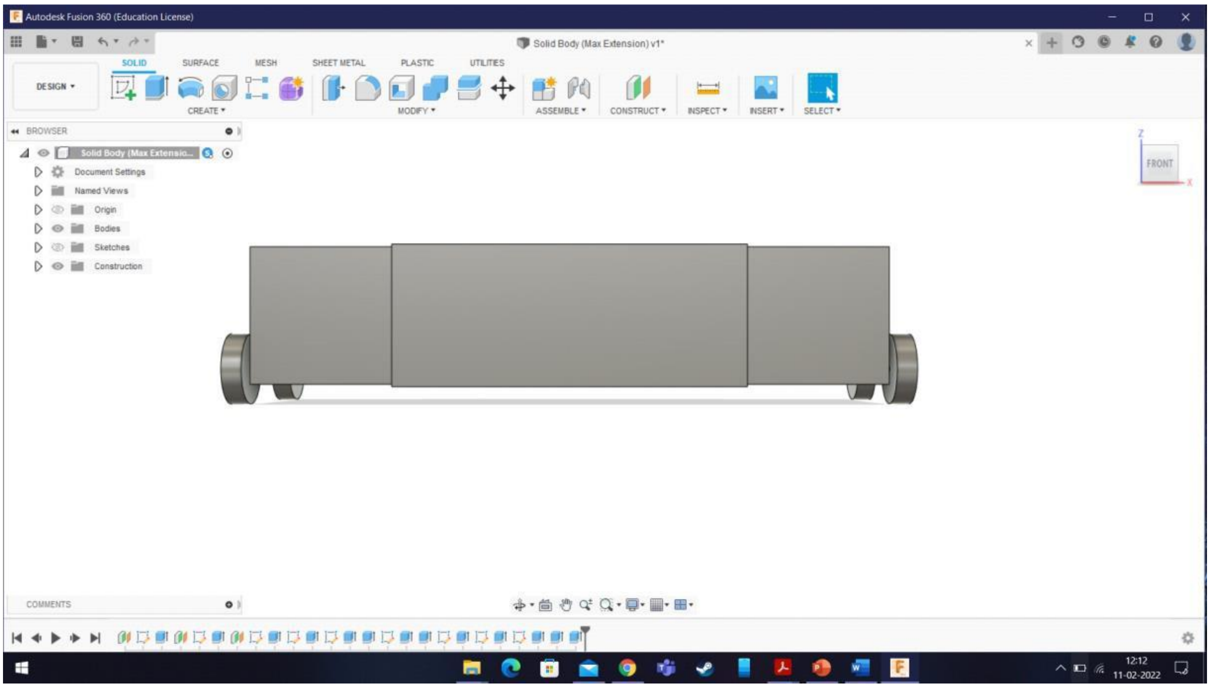
[Figure 14]

i) Working voltage: DC 9V–36V
ii) Output voltage: 5.2V/5A/25W

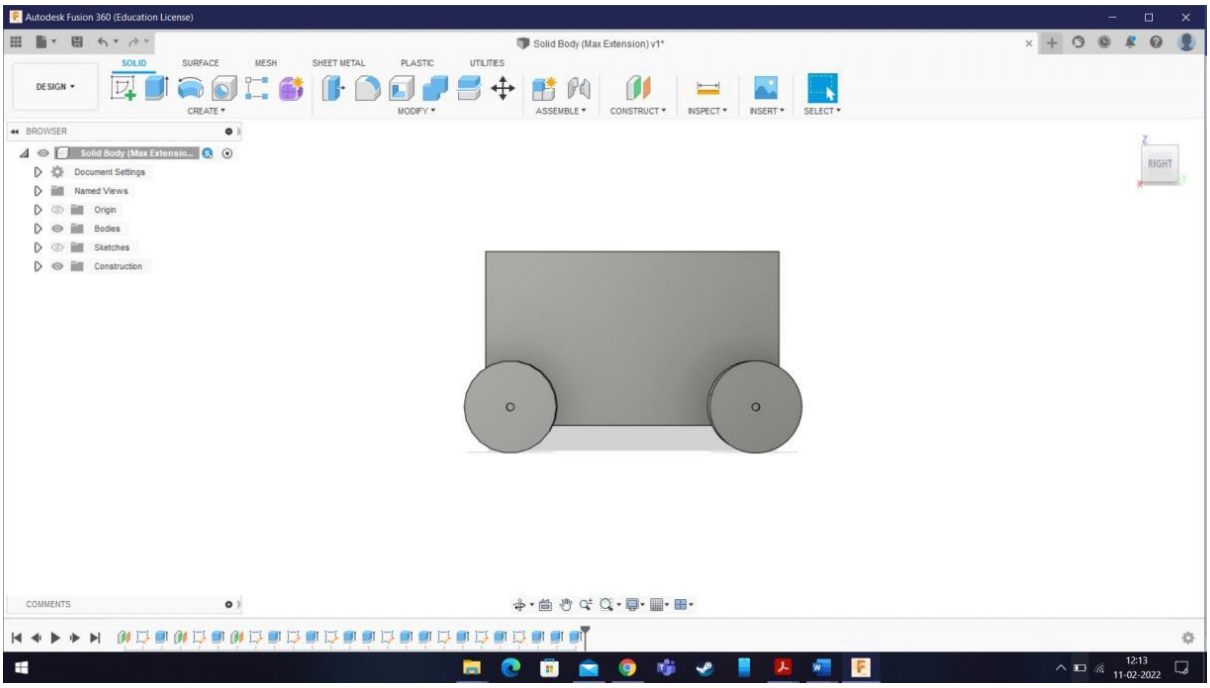
i) 24V to 12V DC -DC Converter
ii) High efficiency of up to 80%

DC/DC converters have been chosen since the robot uses a 24V battery pack. The first DC/DC converted reduces the voltage to 5V for the Raspberry Pi and the on-board sensors. The second one reduces the voltage to 12V for the ball screw actuators and the vacuum pump.

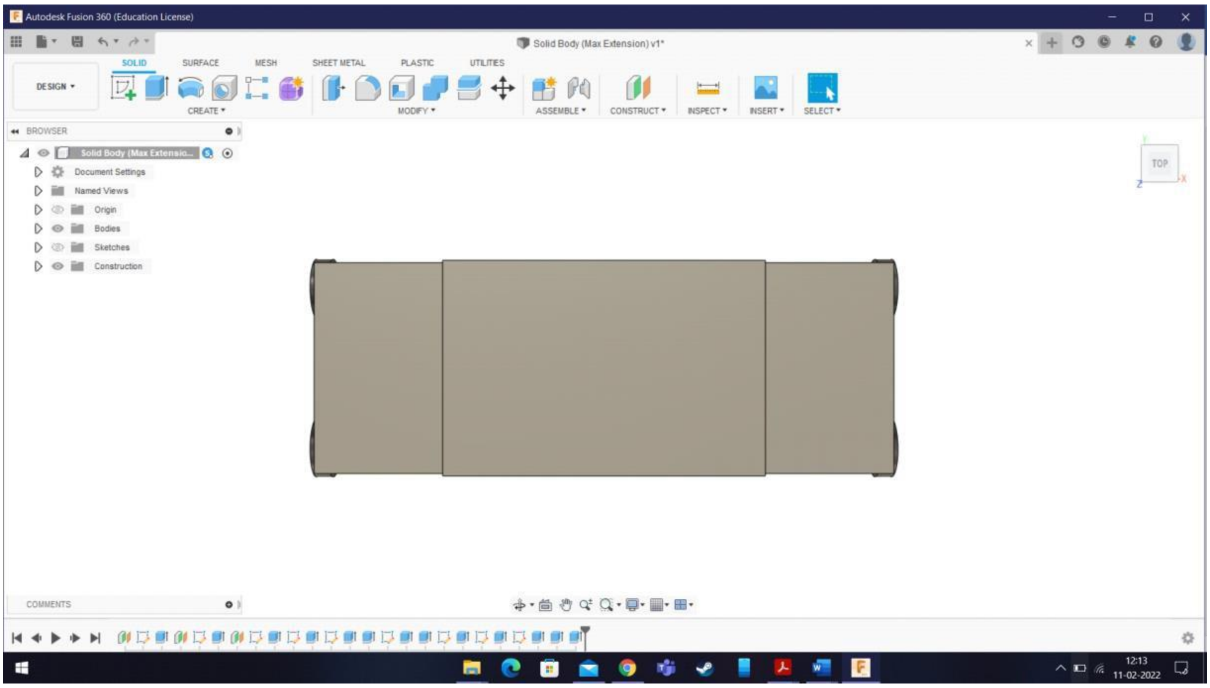
Design Prototype (Review 1):



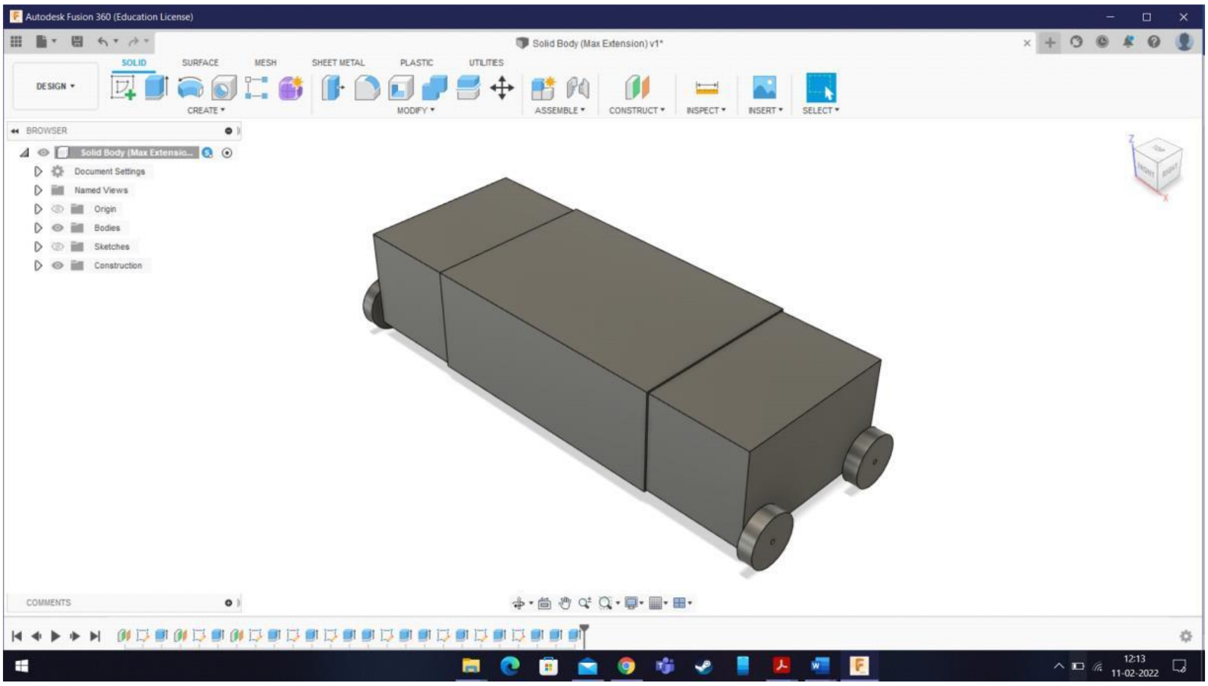
FRONT VIEW



SIDE VIEW



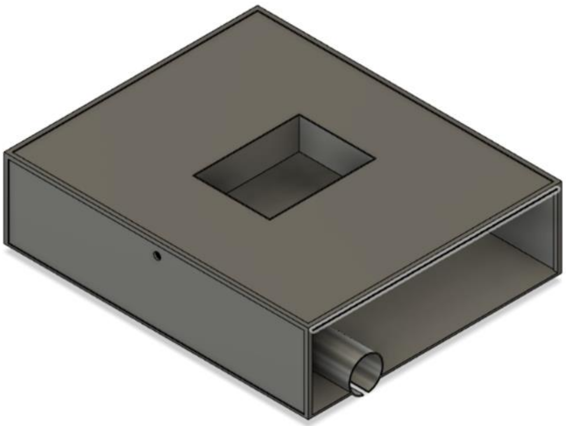
TOP VIEW

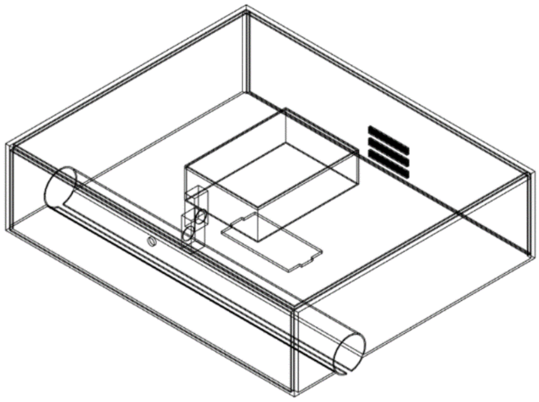


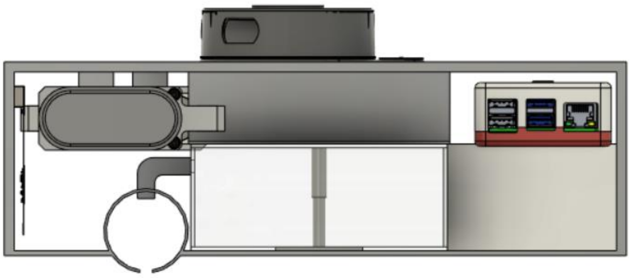
ISOMETRIC VIEW

CAD Design:

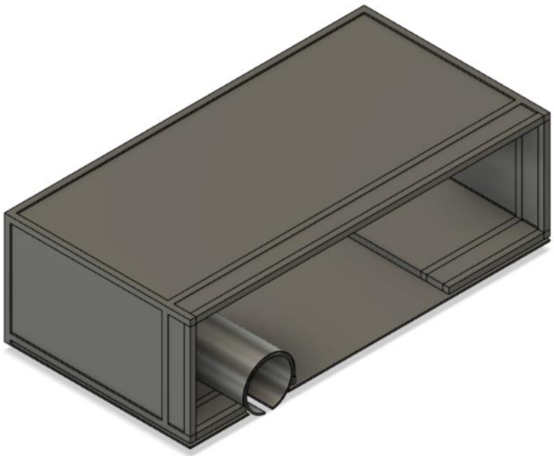
1. Main Box:

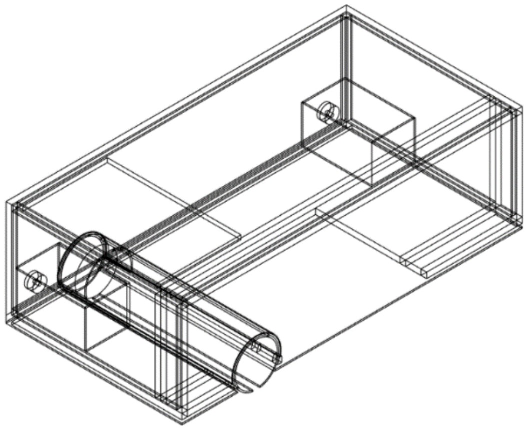


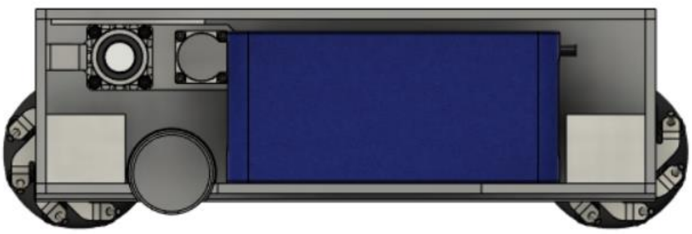




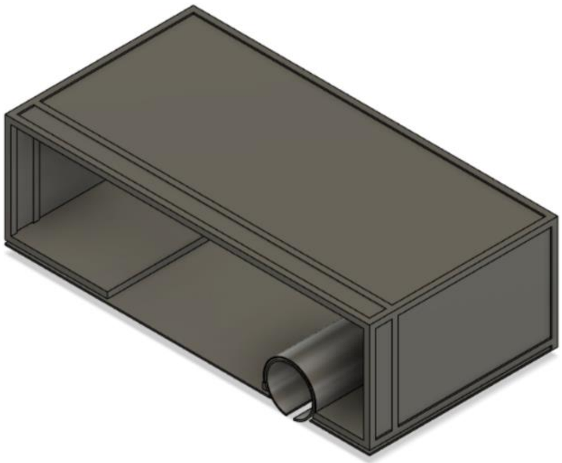
2. Left Box:

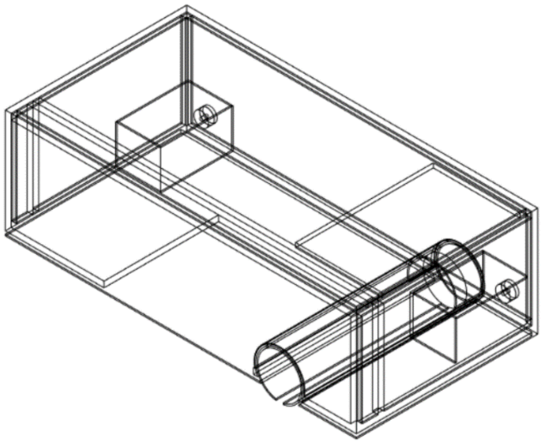


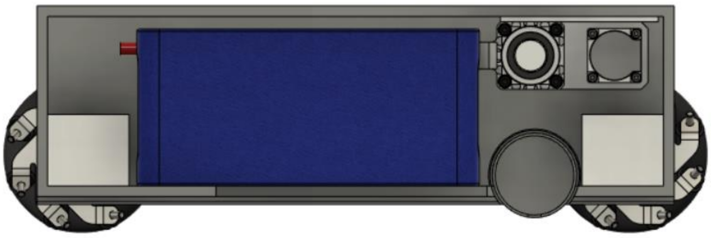




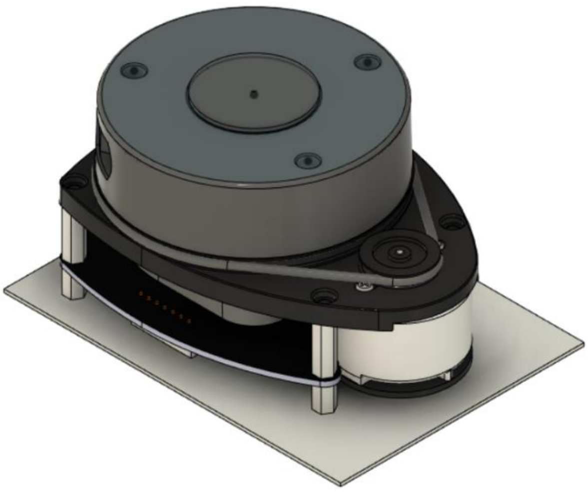
3. Right Box:

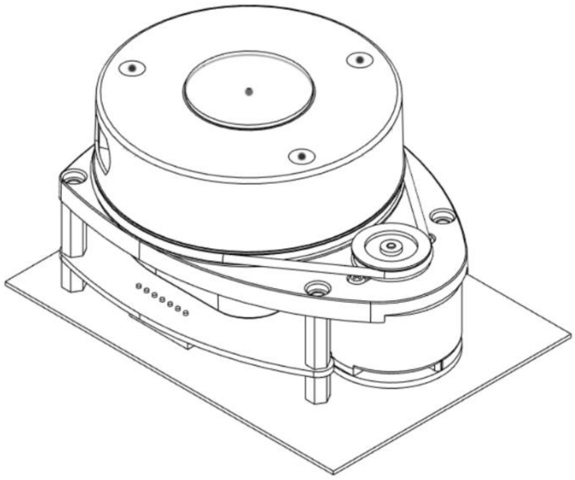




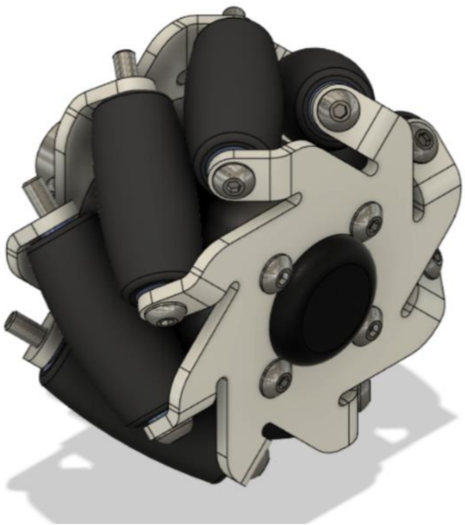


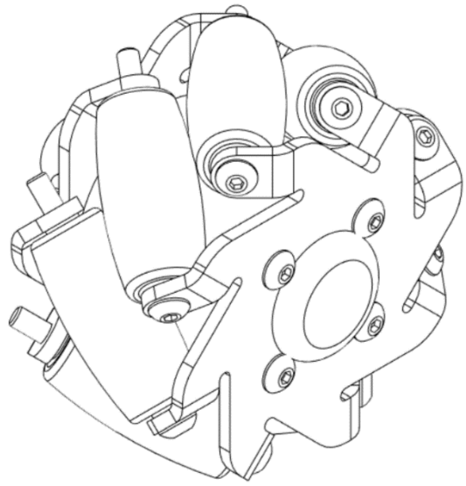
4. LIDAR Scanner:



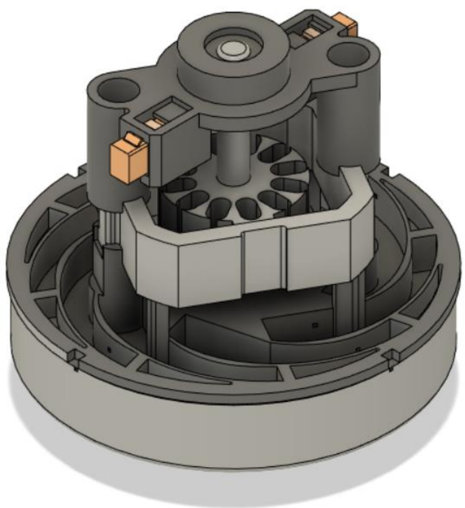


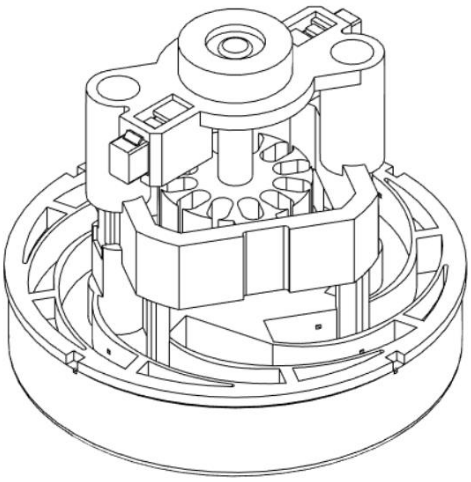
5. Mecanum Wheel:



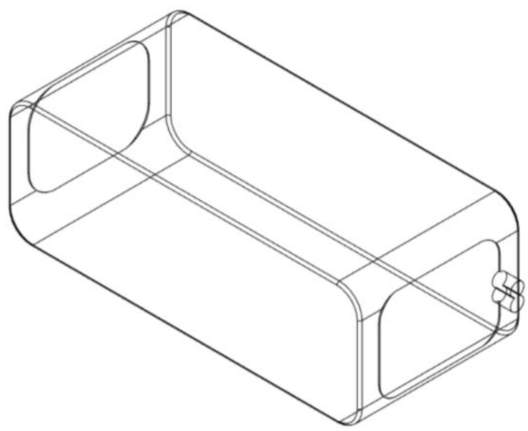


6. Vacuum Pump:

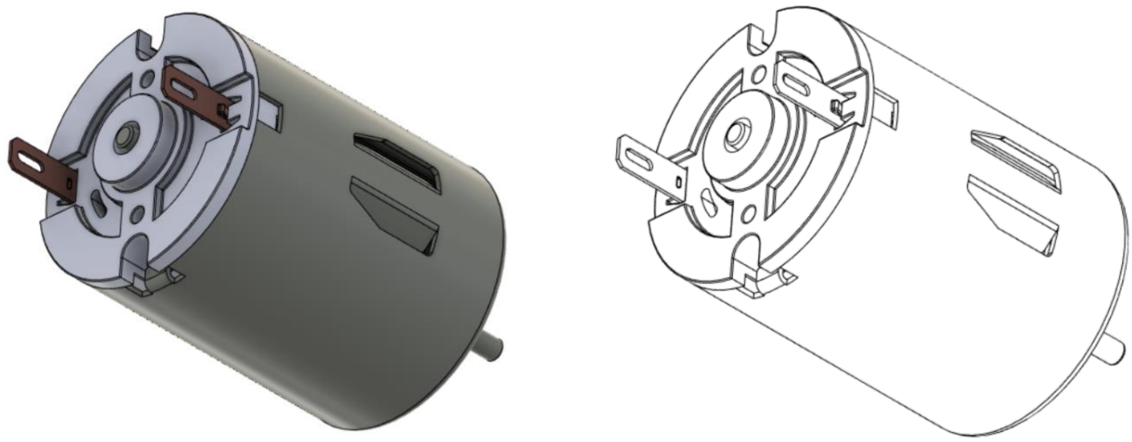




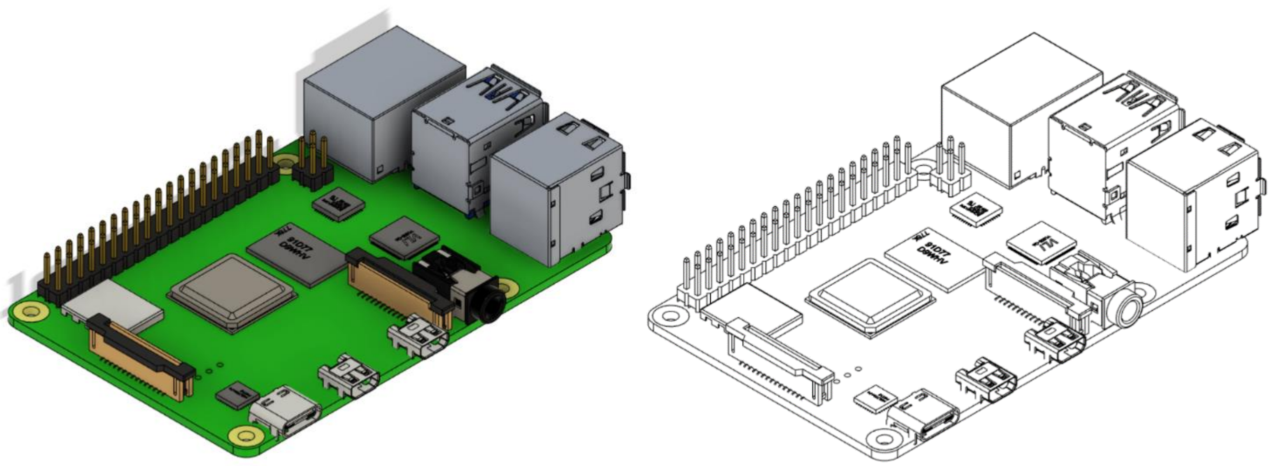
7. Battery Pack:



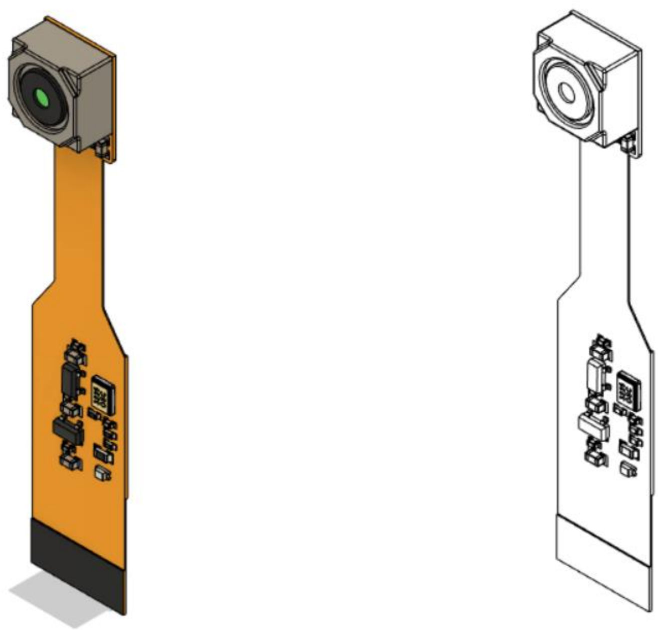
8. Wheel DC Motor:



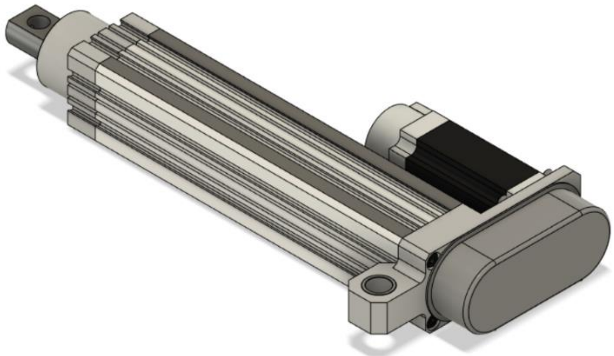
9. Raspberry Pi 4:

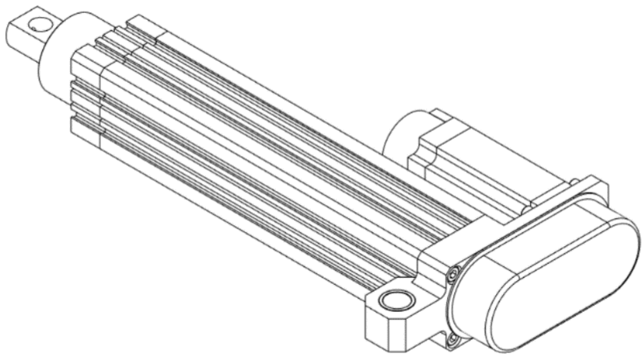


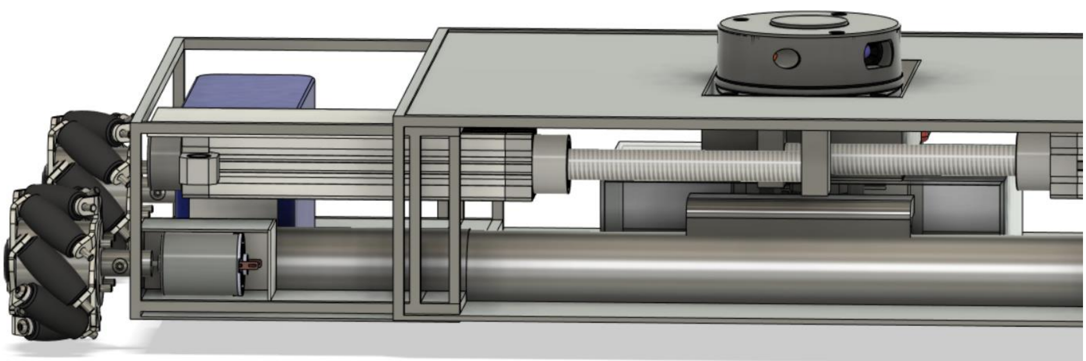
10. Camera:

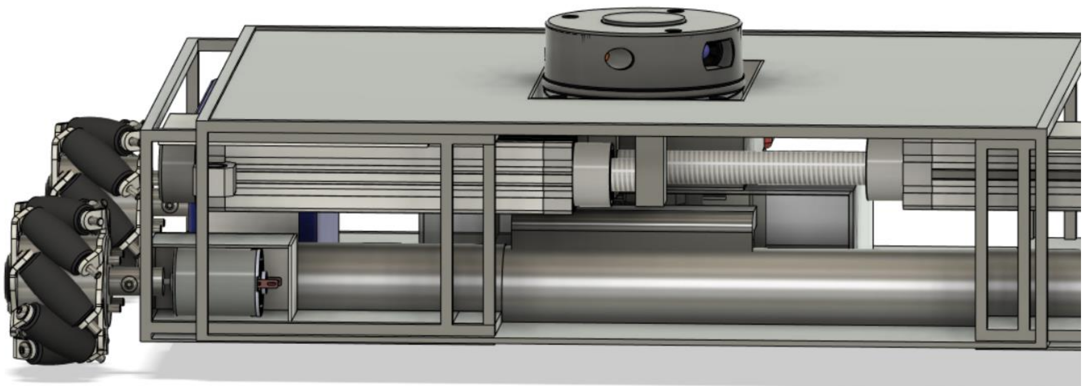


11. <u>Ball Screw Actuator:</u>

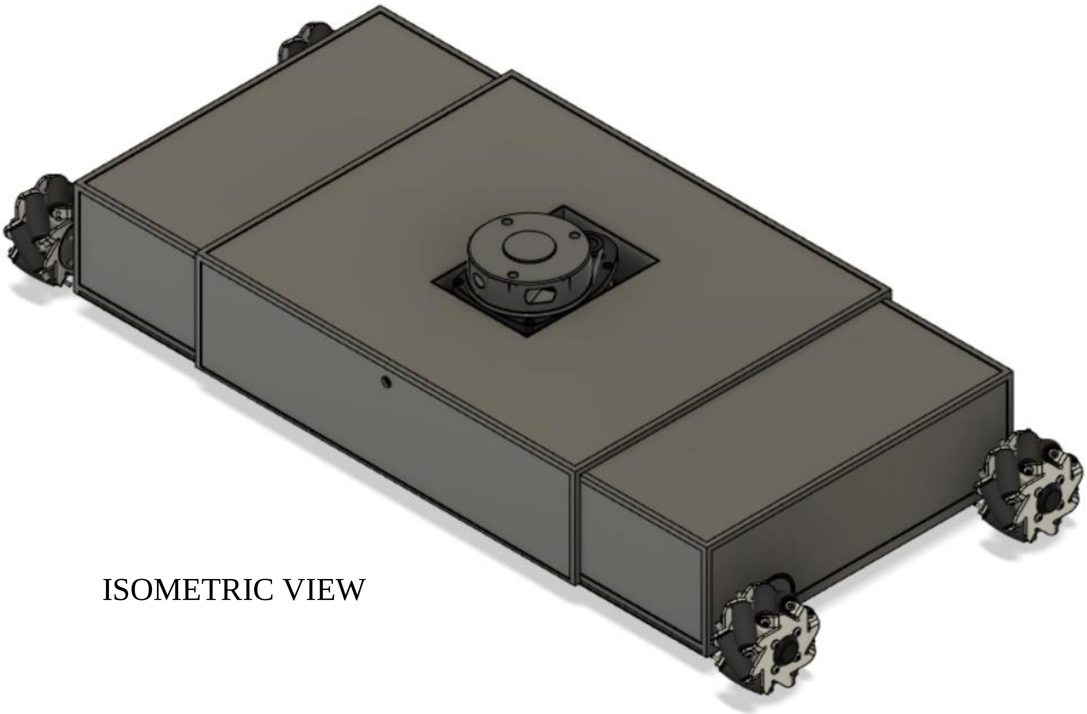






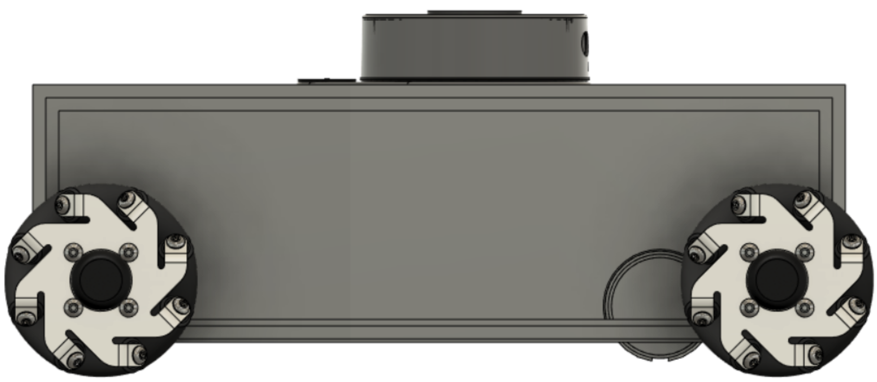


Final Model:

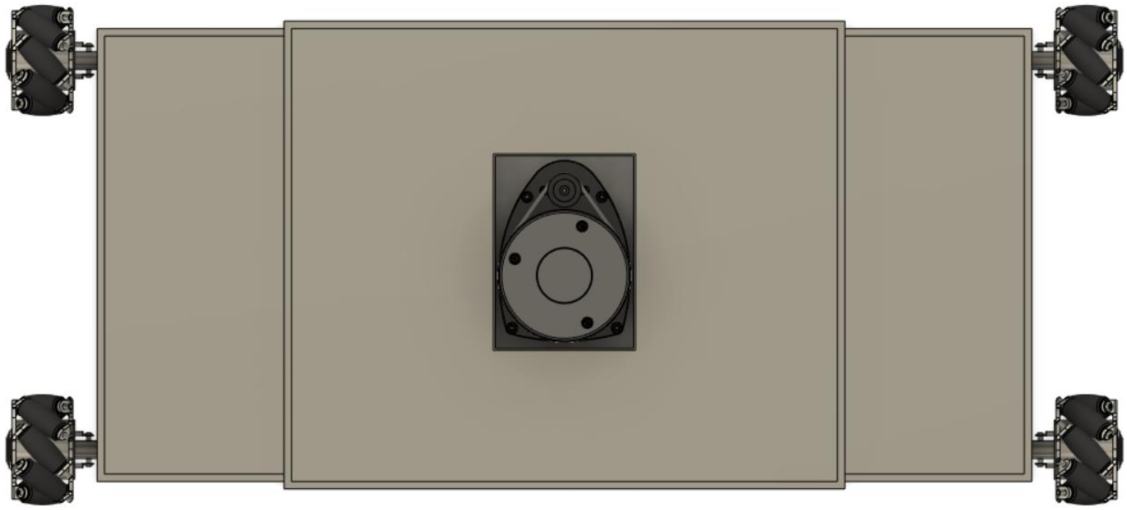


ISOMETRIC VIEW

FRONT VIEW



SIDE VIEW

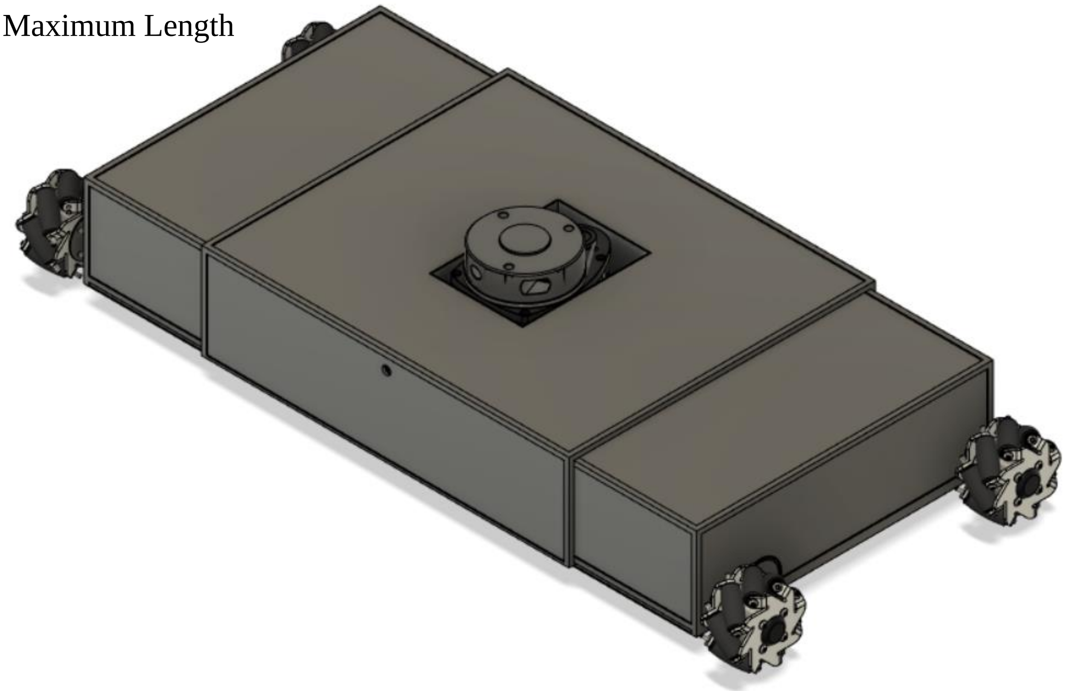


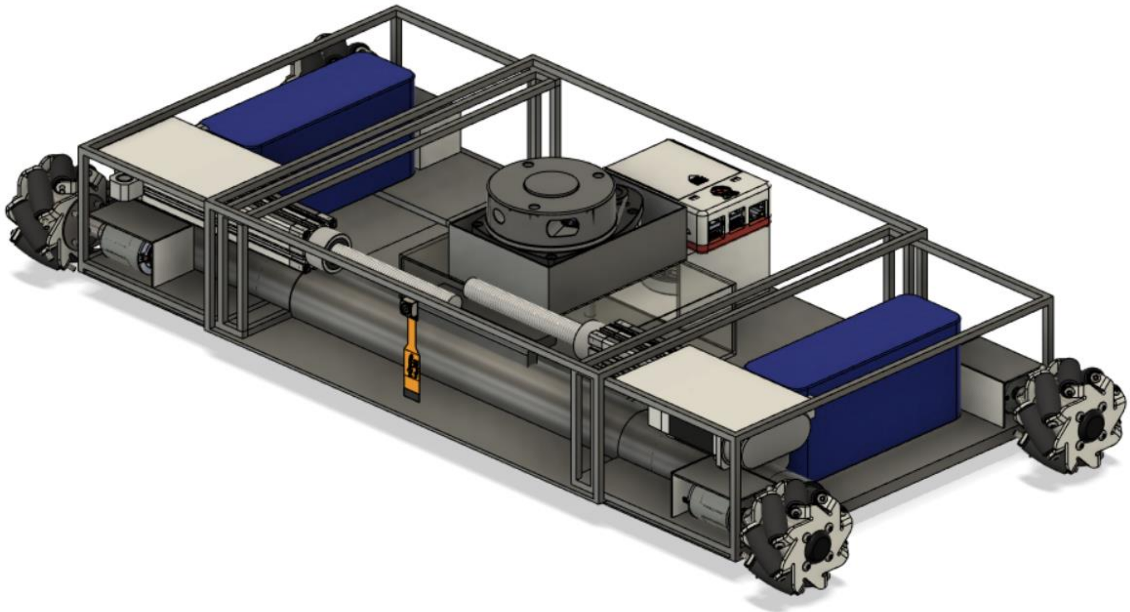
TOP VIEW

BOTTOM VIEW

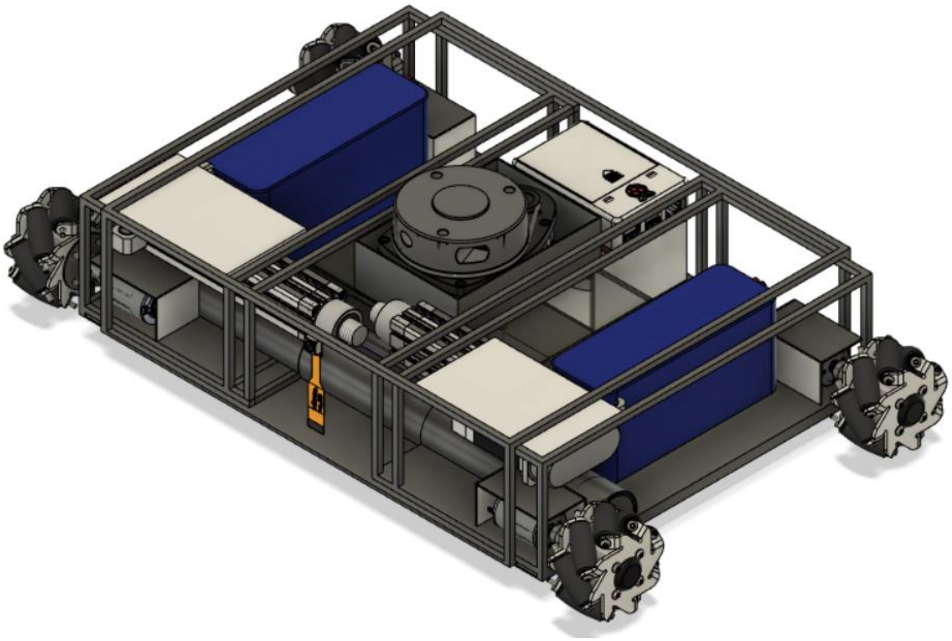
BACK VIEW

Maximum Length





Minimum Length



Simulation:

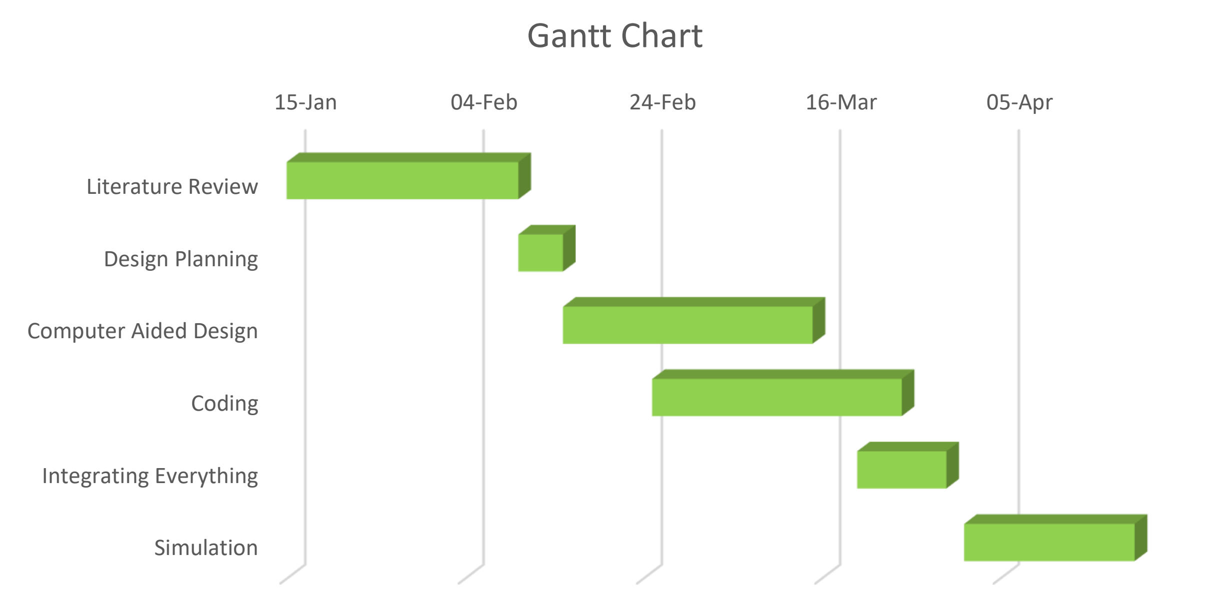
A simulation study has been created to demonstrate and analyse the efficacy and effectiveness of the system. A simplified CAD model has been developed to ensure that the simulation goes smoothly. The CAD model has further been exported as a URDF file, and then imported into the simulation software. The simulation software chosen is CoppeliaSim (V-REP) because of its simplicity and familiarity with the software. Further, the joints and links have been defined, sensors integrated, and the scene set. The robot is able to move and also change its size effectively.

https://drive.google.com/file/d/19EQk5tqUa7tWNCU656DGSFBoZz20wXNN/view?usp=sharing

Work to be Done:

1. Integration of SLAM and object detection using LIDAR and camera- Simultaneous Localization and Mapping will be used by the cleaning robot to create a map of the terrain and the concept of Light Detection and Ranging is used which collects information about variable distances between the robot and an obstruction using light in the form of a pulsed laser.
2. Development of the control system for the Mecanum wheels, and for actuating the Ball Screw Linear Actuator for changing the size (length) of the robot.
3. Integration of Dijkstra algorithm for path planning, along with object detection.
4. Conduction of a Simulation study to demonstrate the efficacy of the system.
5. Conduction of Stress Analysis on the robot.

Gantt Chart:



	Simulation	Integrating Everything	Coding	Computer Aided Design	Design Planning	Literature Review
Start Date	01-Apr	20-Mar	25-Feb	15-Feb	10-Feb	15-Jan
Days to Complete	20	10	28	28	5	26

Milestones in the Project Phase:

1. Completion of Chassis Design
2. Development of CAD Design for Actuation Mechanism
3. Development of Path Planning Algorithm
4. Development of Object Detection Algorithm
5. Development of the control system to actuate the Ball Screw Linear Actuator used to change the size of the robot
6. Conduction of Simulation study

Summary:

Cleaning robots have advanced significantly in recent years, owing to increased market presence and the demand for improved cleaning performance. However, due to geometric restrictions of the platforms in relation to the cleaning stage, as well as furniture and architecture, most robots have difficulty covering the whole cleaning area. The aim is to use the on-board sensors which will mainly be used for SLAM (Simultaneous Localization and Mapping) integrated using LIDAR and camera to detect obstacles and change the robot configuration accordingly and to navigate forward and backward and even sideways with the help of Mecanum wheels. The plan is to use a ball screw actuation mechanism to change the length of the robot according to what it maps about the local terrain using the sensors. A precise CAD model will be designed with parameters so as to bring down cost of making the cleaning robot to the bare minimum while also optimizing its cleaning efficiency at the same time.

From the CAD design point of view, the robot comprises 3 hollow cuboid compartments that overlap and can linearly actuate with the help of the ball screw mechanism. The vacuum system comprises a set of rigid concentric pipes, and there will be a slit along the length of the pipe which will make the vacuum opening. The ends of these pipes will be attached to the walls of the robot on both sides. Hence, whenever the pipes will move further away from each other the slit opening will also increase making it more efficient to collect dust. These pipes will be connected to a storage compartment via a connecting pipe.

Increasing the area of the vacuum opening will reduce the suction power so to overcome this problem a motor will be inserted which will adjust the suction power based on the largest opening. For example, when the robot is fully extended it will be powerful enough to absorb dust at the largest opening and when the opening size reduces i.e., when the robot contracts, the vacuum motor voltage will automatically be reduced using a buck converter in order to maintain a constant suction pressure.

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