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ABSTRACT

Cleaning robots have advanced significantly in recent years, owing to their increased market presence and the desire for improved performance in cleaning. However, owing to their geometric restrictions with respect to the cleaning area, most robots have difficulty in cleaning the entire area. The robot developed in this paper uses on-board sensors, including ultrasonic sensors and camera to detect obstacles, change the robot configuration accordingly, and navigate forward, backward and even sideways with the help of Mecanum wheels. a ball screw linear actuator has been used to change the length of the robot according to what it maps about the room using the sensors. For this purpose, a precise CAD model has been developed according to the decided parameters. A functional prototype has also been developed as a proof of concept and it has been compared with a simulation study done in CoppeliaSim software.

INDEX TERMS: Floor Cleaning Robot, Linear Actuator, Mecanum Wheels

1. 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 deployed in homes and offices to clean the floors.

According to a world market study, there is a high demand for these robots in domestic settings with fully automated functionalities and minimum human assistance, and while these robots still account for a small percentage of the vacuum cleaner in the market, their popularity 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, and basic zig-zag motion.

Even though fixed-configuration robots have sufficient path planning and motion skills, they may require more energy and time 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.

A functional prototype has been developed with the decided components as mentioned and exhaustive testing and simulations on the control mechanism have also been performed for introduction to the commercial market in the later stages.

1.1 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 [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 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 signifies the robot position, and the chromosomes signify the mini-path [13].

Liu et al. developed an algorithm for complete coverage path planning, which is a combination of 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 manoeuvres 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].

Zhao et al. developed a path planning algorithm based on bidirectional associative learning [23]. Lakshmanan et al. developed a complete coverage path planning algorithm based on reinforcement learning [24]. Yan et al. worked on a robot with a scrubber and its perception system [25]. Wang et al. worked on Dijkstra Algorithm for the purpose of path planning [26]. Several 3D path planning algorithms have also been surveyed and experimented with [27].

Elara et al. conducted a case study on a Roomba robot, as it is widely regarded as the benchmark for cleaning robots [28]. Jones et al. also analysed the Roomba [29]. Several other researchers have also studied the Roomba as it is the most popular cleaning robot [30]. Tribelhorn et al. also put forth a study on the Roomba [31].

Bergman et al. presented a study on robot vacuum cleaners [32]. Asafa et al. developed a robot vacuum cleaner of their own with an aim to improve efficiency [33]. Zhang et al. worked on path planning of mobile robots using A-Star and Dijkstra Algorithms [34]. A simple local path planning algorithm has also been developed [35]. Adithya et al. developed a autonomous mopping and cleaning robot [36]. Ilyas et al. developed a reconfigurable robot named sTetro [37]. Ichimura et al. worked on a cleaning robot named Hirotarro for use in beaches [38].

Shah et al. worked on an autonomous and manual floor cleaning robot [39]. Silva et al. integrated LIDAR and camera for mapping and obstacle detection in an autonomous cleaning robot [40]. Lima et al. developed an enhanced Mecanum wheel [41].

2. METHODOLOGY

2.1 FUNCTIONAL ARCHITECTURE

The battery pack will power the on-board sensors, which include Ultrasonic sensors, IMU and Camera. These sensors will in turn provide input data to the Raspberry Pi, which is the microprocessor being used. The Raspberry Pi will in turn carry out and manage the various subsystems using the input data from the sensors. The various subsystems include Localization, Path Planning, Obstacle Detection, Locomotion, and Resizing.

The locomotion is carried out using four Mecanum Wheels connected to DC Motors, using a motor driver. Resizing is carried out using the Ball Screw Linear Actuator via another motor driver.

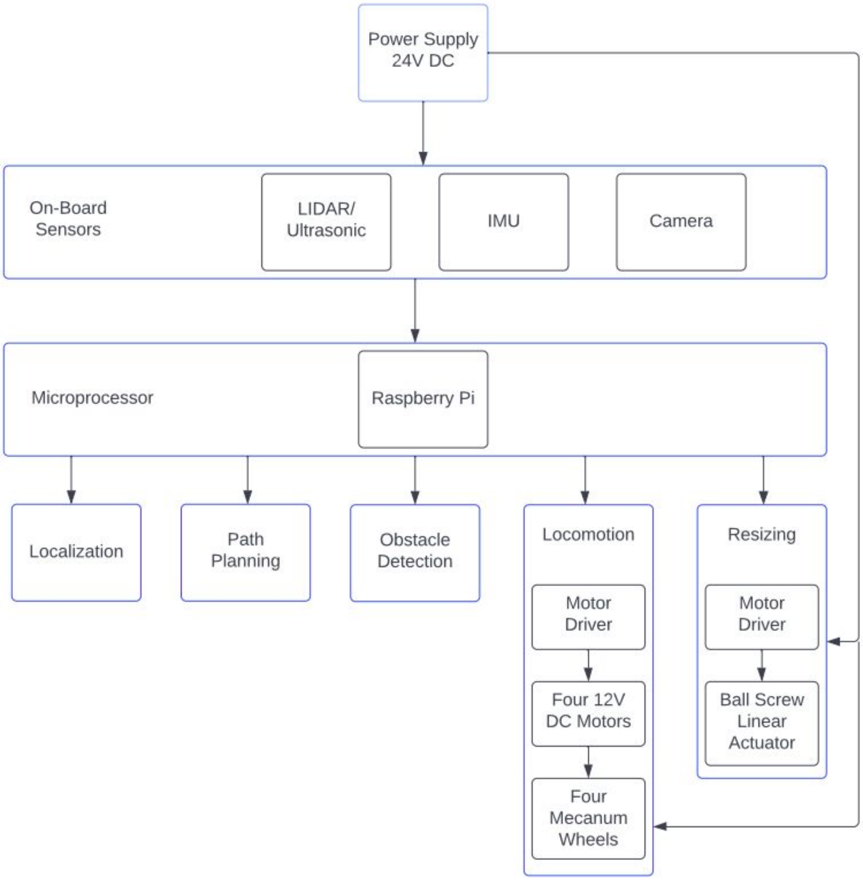

Fig. 1 Functional Architecture

2.2 PROCESS FLOWCHART

The robot will function based on a fixed set of logical decisions, as illustrated in the flowchart above, which will ensure efficient and reliable cleaning. In open spaces, the robot will try to increase is lengths as much as possible. In case there is an obstacle, it will first try to reduce its length to pass through the obstacle. If it is unable to do so, it will simply manoeuvre around the obstacle and continue cleaning.

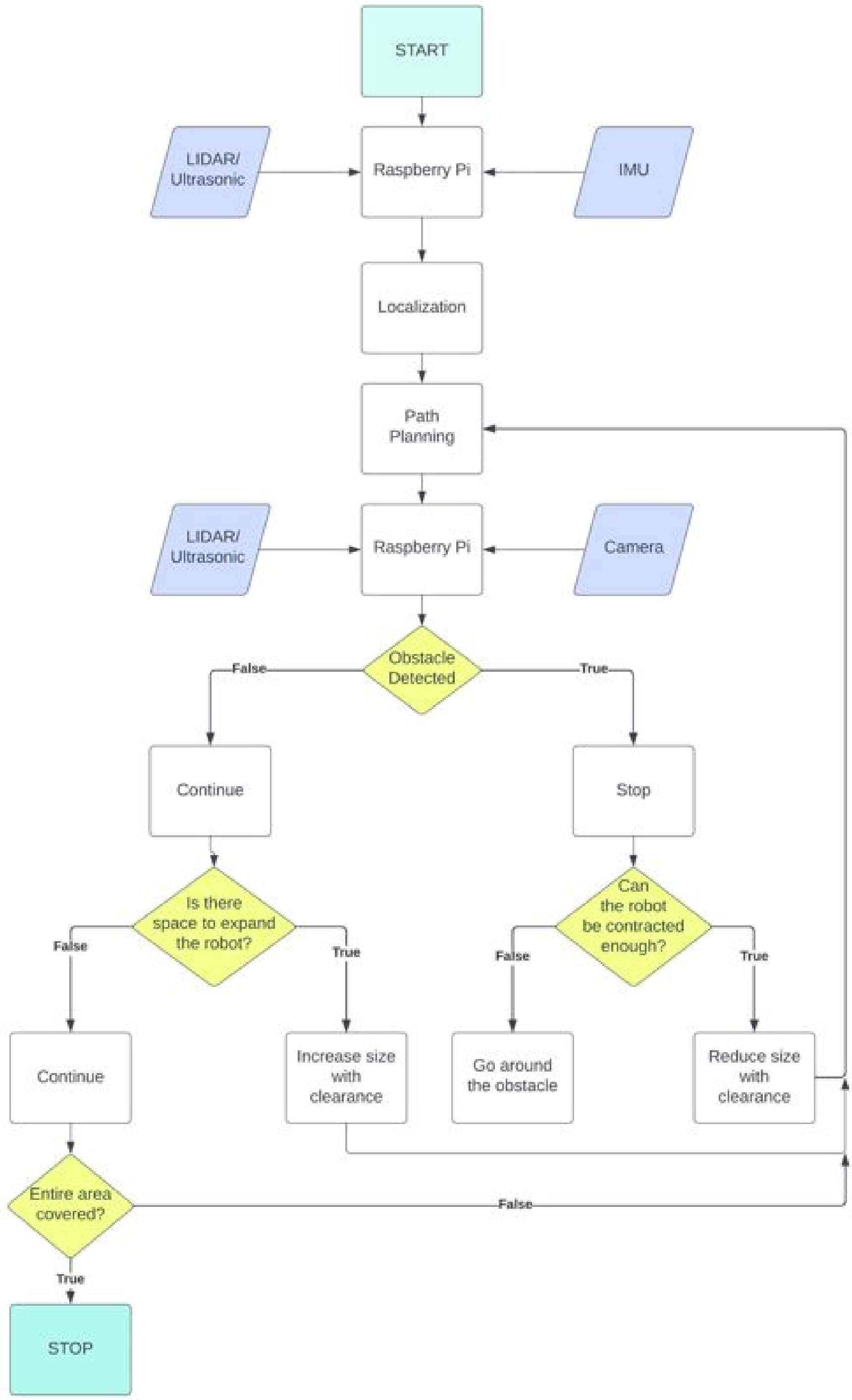

Fig. 2 Robot's Process Flowchart

2.3 CONTROL MECHANISM

2.3.1 ULTRASONIC SENSORS

The operation of ultrasonic sensors is similar to that of radar sensors. The transmitter in a radar system produces radio waves (sound waves), which are electromagnetic waves that move through the air and return when they collide with an object in their path. The distance is then determined using the following simple formula.

Distance= Time x Speed

Time- amount of time taken by the sound wave to travel from the detected object to the receiver.

Speed- Sound wave speed

Most ultrasonic sensors consist of a trigger that transmits infrared sound waves and a receiver that records the reflected sound waves which is used for the basic purpose of object detection by the cleaning robot.

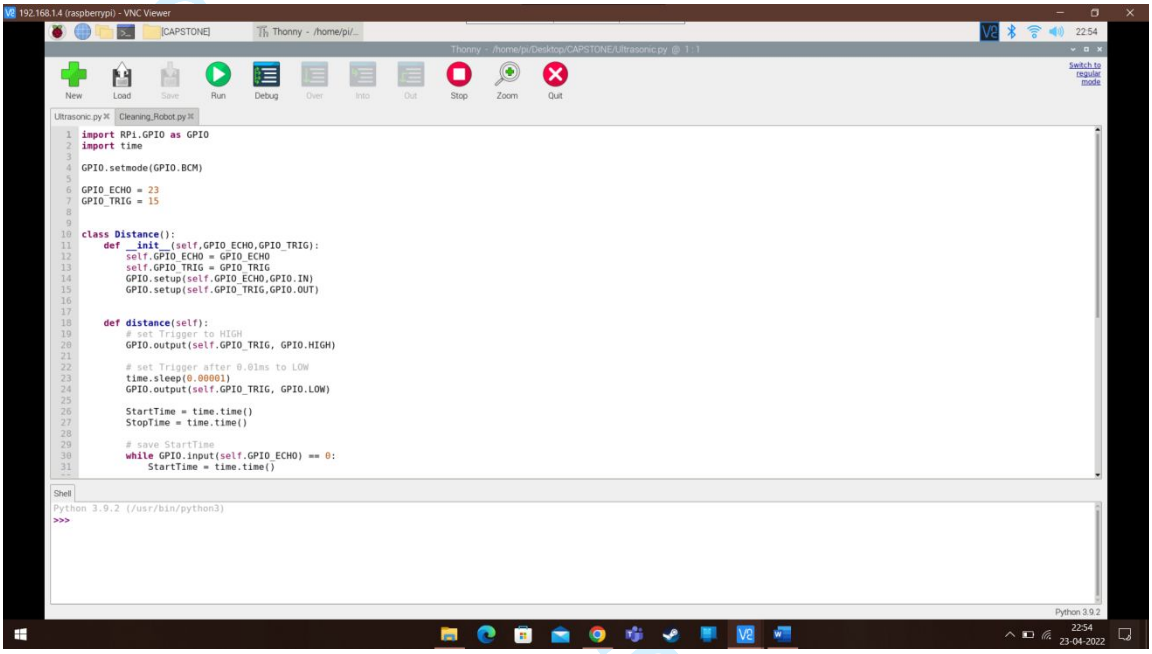

Fig. 3 Ultrasonic Sensor Code

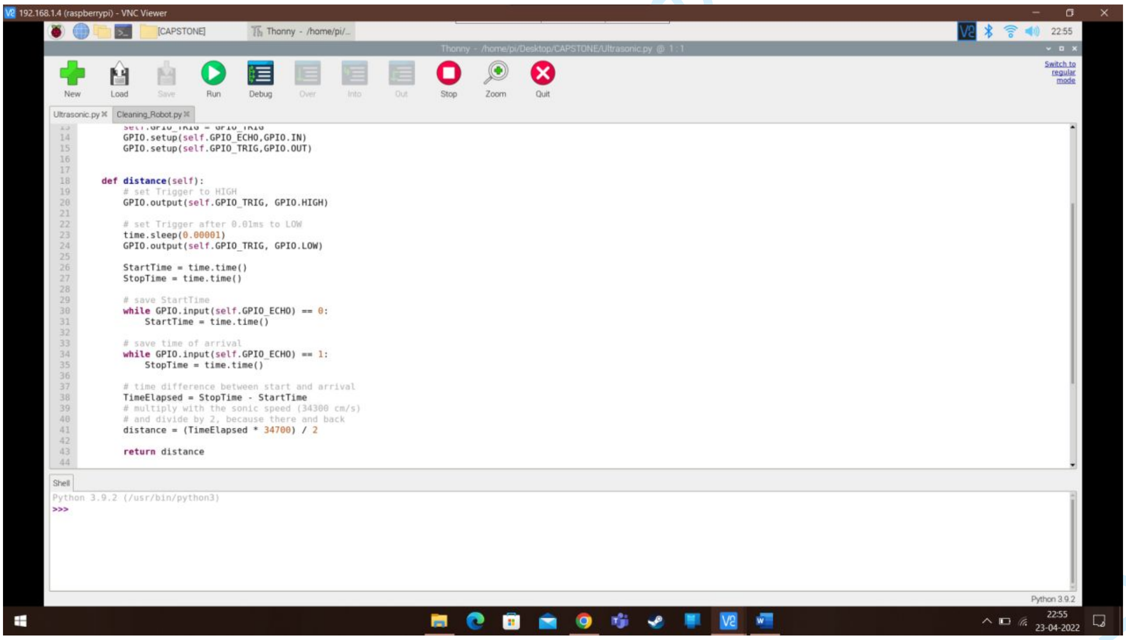

Fig. 4 Ultrasonic Sensor Code contd.

2.3.2 MAIN SCRIPT

The main script will run the robot. It will call the functions from the Ultrasonic file, and the Motor Class. It will then actuate the motors using the functions from the Motor Class, based on the inputs from the ultrasonic sensors.

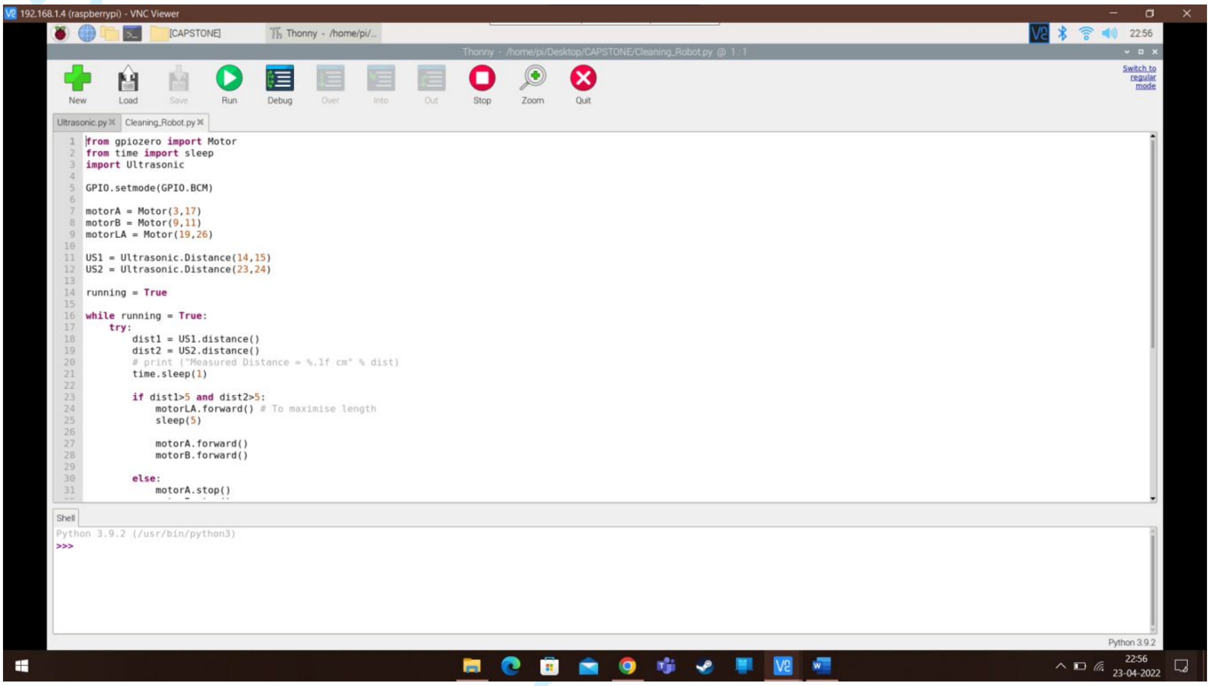

Fig. 5 Main Script

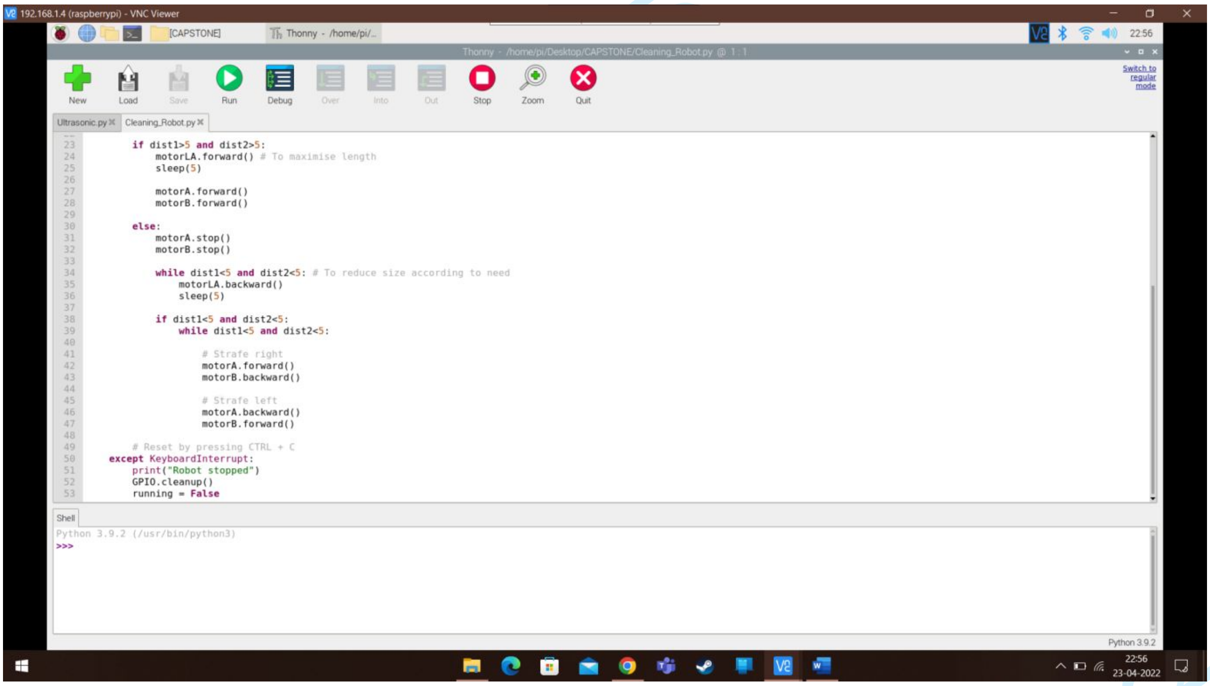

Fig. 6 Main Script contd.

2.4 COMPONENTS

The primary components that have been used are:

1. Mecanum Wheels – Mecanum wheels enable excellent manoeuvrability and ability to move in a congested space.

   Mecanum wheels with the following specifications have been chosen:

   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

2. Camera – A camera sensor for object detection has been chosen so as to facilitate the cleaning robot to make its own autonomous decision and to transmit a live video feed to any device via Wi-Fi. The camera module chosen is the Raspberry PI 5MP Camera Board Module.

3. Raspberry Pi 4 – A Raspberry Pi 4 microprocessor has been chosen because of its hardware integration and the capacity to handle complicated tasks effectively and simultaneously. Raspberry Pi 4 will be used specifically due to its high-performance 64-bit quad-core processor, 2 GB of RAM and GPIO capabilities.

4. Battery Pack – The battery pack chosen consists of two 5000mAh 22.2V battery packs with maximum discharge current and maximum charging current as 15000 mA and 5000 mA respectively. The two 5000mAh battery are connected in parallel so that the voltage remains constant and the battery backup improves.

5. IMU – A MPU9250 9-Axis Attitude Gyro Accelerator Magnetometer Sensor Module with a power supply of 3.3-5 V (DC) has been chosen. It has 9 DOF.

6. Wheel Motor – Four DC Motors with High Power Density and high efficiency have been chosen. The following are their 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

7. Ball Screw Linear Actuator – A Ball Screw Linear Actuator has been chosen as it the component that will enable the robot to adjust its size. Ball screw actuators are mechanical linear actuators which consist of a screw shaft and a nut with a ball that rolls between helical grooves that correspond. Ball screws' main purpose is to convert rotational motion into linear motion. Ball nuts are used to transmit forces to a static or dynamic loads with excellent precision, reproducibility, and accuracy. The rolling balls in the helical groove of ball screws greatly reduce friction. Screw efficiency is determined by their capacity to convert power used to exert rotating force into linear distance travelled.

8. Chassis - A functional prototype was developed wherein mild steel sheet metal was used to construct the chassis. The reasons for using mild steel are its properties:

   i) Cost Effective
   ii) Weldable
   iii) Ductile
   iv) Can be carburised easily
   v) Recyclable

Table 1. List of Components

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
Ultrasonic Sensor	2	HC-SR04	5 x 4 x 3 cm	14g (x2)	75 (x2)

2.5 DESIGN CALCULATIONS

2.5.1 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. Case 3 (Marble):

   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. Case 4 (Smooth Concrete):

   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. Case 5 (Rough Concrete):

   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

2.5.2 **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

$$Q = Av$$

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

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

2.5.3 **Battery Life Calculations:**

The essential Components are:

i) Units of Motors = 15*4 = 60 W
ii) Vacuum Pump = 40 W
iii) RPLIDAR A1 = 0.5 W
iv) Camera = 7.5 W
v) 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)

2.6 **CIRCUIT**

2.6.1 **ULTRASONIC SENSORS**

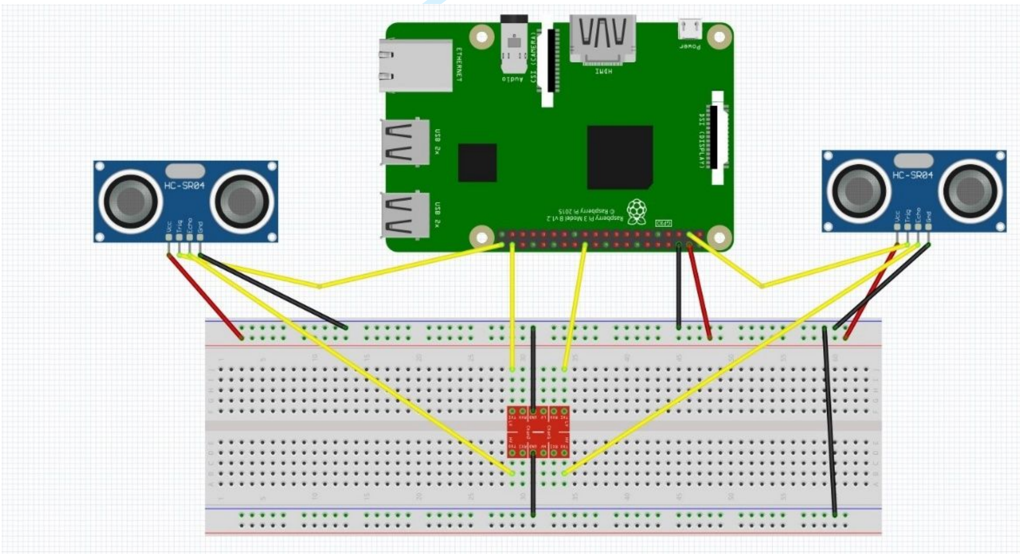

Fig. 7 Ultrasonic Sensors Circuit

Fig. 7 shows the various connections made between the Raspberry Pi and the HC-SR04 Ultrasonic sensors. The Ultrasonic sensors are powered via the +5V pins of the Raspberry Pi. The Grounds are made common. The TRIG pin of the sensor is set as an output pin, and is connected to one of the several GPIO pins of the Raspberry Pi. The ECHO pin of the sensor is set as an input pin. Since the HC-SR04 sensor functions on a 5V logic level, and the Raspberry Pi on a 3.3V logic level, connections have to be made via a 5V to 3.3V logic level shifter.

2.6.2 **WHEEL MOTORS**

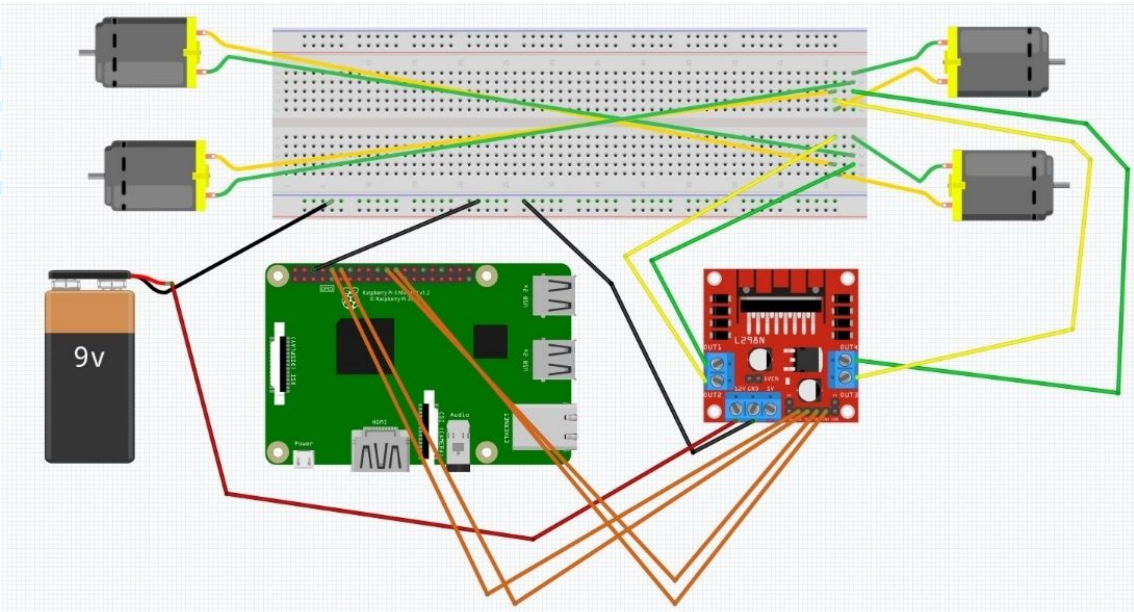

Fig. 8 Wheel Motors Circuit

Fig. 8 shows the connections between the Raspberry Pi, motors and the motor driver. Diagonally opposite motors, corresponding to the type A and type B Mecanum wheels respectively, are connected together. The positive and negative terminals are then connected to the OUT ports of the L298N motor driver. The motor driver is powered using a 12V battery via the +12V port. The Grounds are made common. Logical connections are made between the IN ports of the motor driver and the GPIO pins of the Raspberry Pi. The ENA and ENB pins of the motor driver can be used for PWM control, to control the speed of the motors.

2.6.3 LINEAR ACTUATOR MOTORS

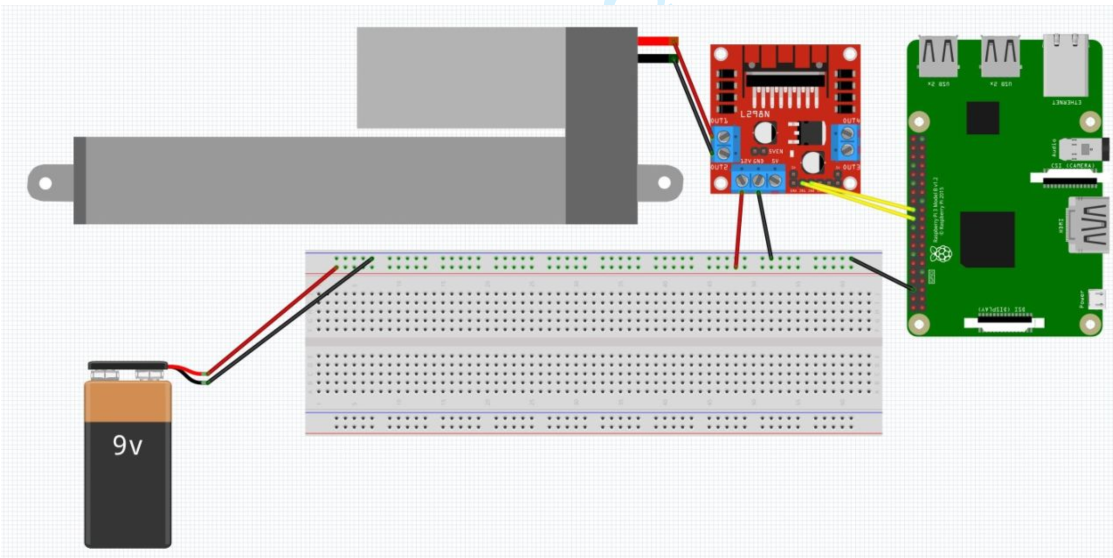

Fig. 9 Linear Actuator Circuit

Fig. 9 shows the connections between the Raspberry Pi, linear actuator and the motor driver. The positive and negative terminals of the linear actuator motor are connected to the OUT ports of the L298N motor driver. The motor driver is powered using a 12V battery via the +12V port. The Grounds are made common. Logical connections are made between the IN ports of the motor driver and the GPIO pins of the Raspberry Pi.

3. RESULTS AND DISCUSSION

3.1 STRESS ANALYSIS

A static stress analysis has been conducted on the MS sheet used to make the chassis of the robot. The software used in Autodesk Fusion 360. The applied load is 20N. Two studies have been created - one when the robot is fully retracted, and another when it is fully extended.

Table 2. Properties of MS [42]

Properties	Values
Young's Modulus	200 GPa
Poission's ratio	0.31
Density	7750 Kg/m^3
Tensile Yield Strength	320 MPa
Tensile Ultimate Strength	400 MPa

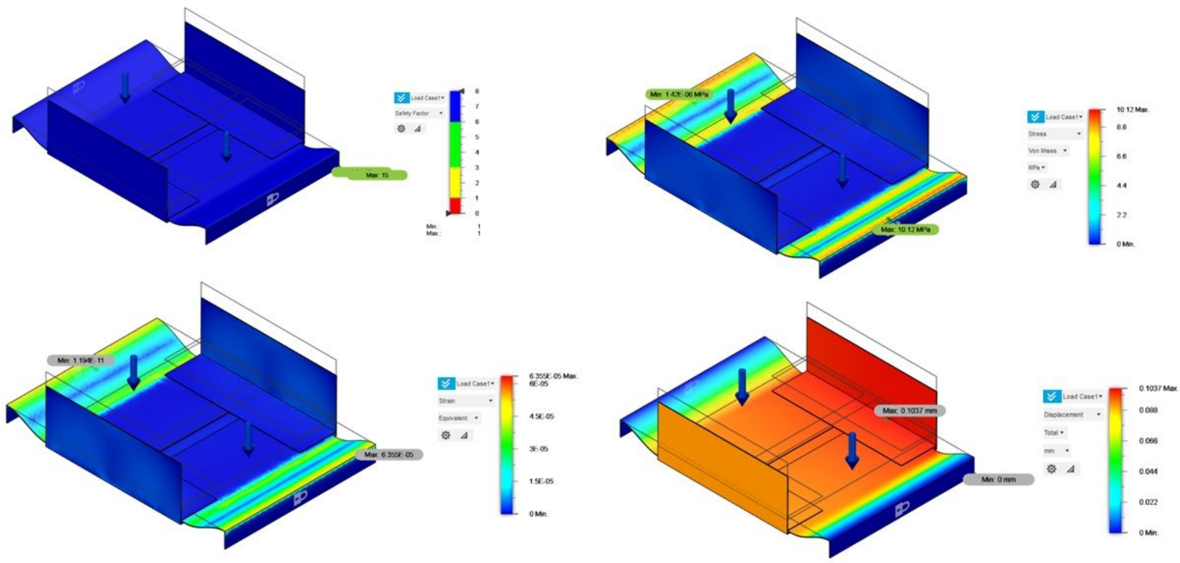

Fig. 10 Stress Analysis (Fully Retracted)

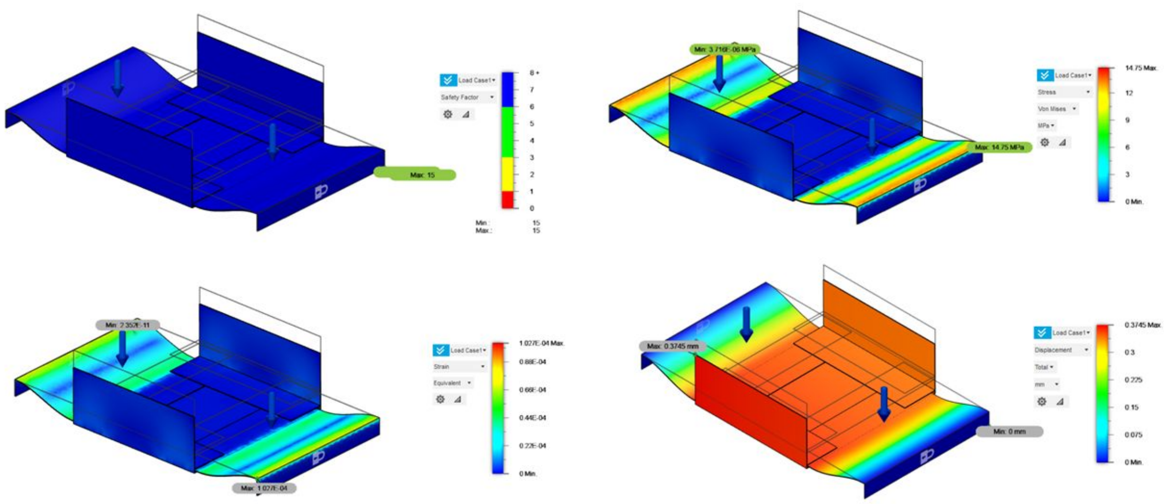

Fig. 11 Stress Analysis (Fully Extended)

3.2 SIMULATION STUDY IN COPPELIASIM SOFTWARE

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 can move and change its size effectively.

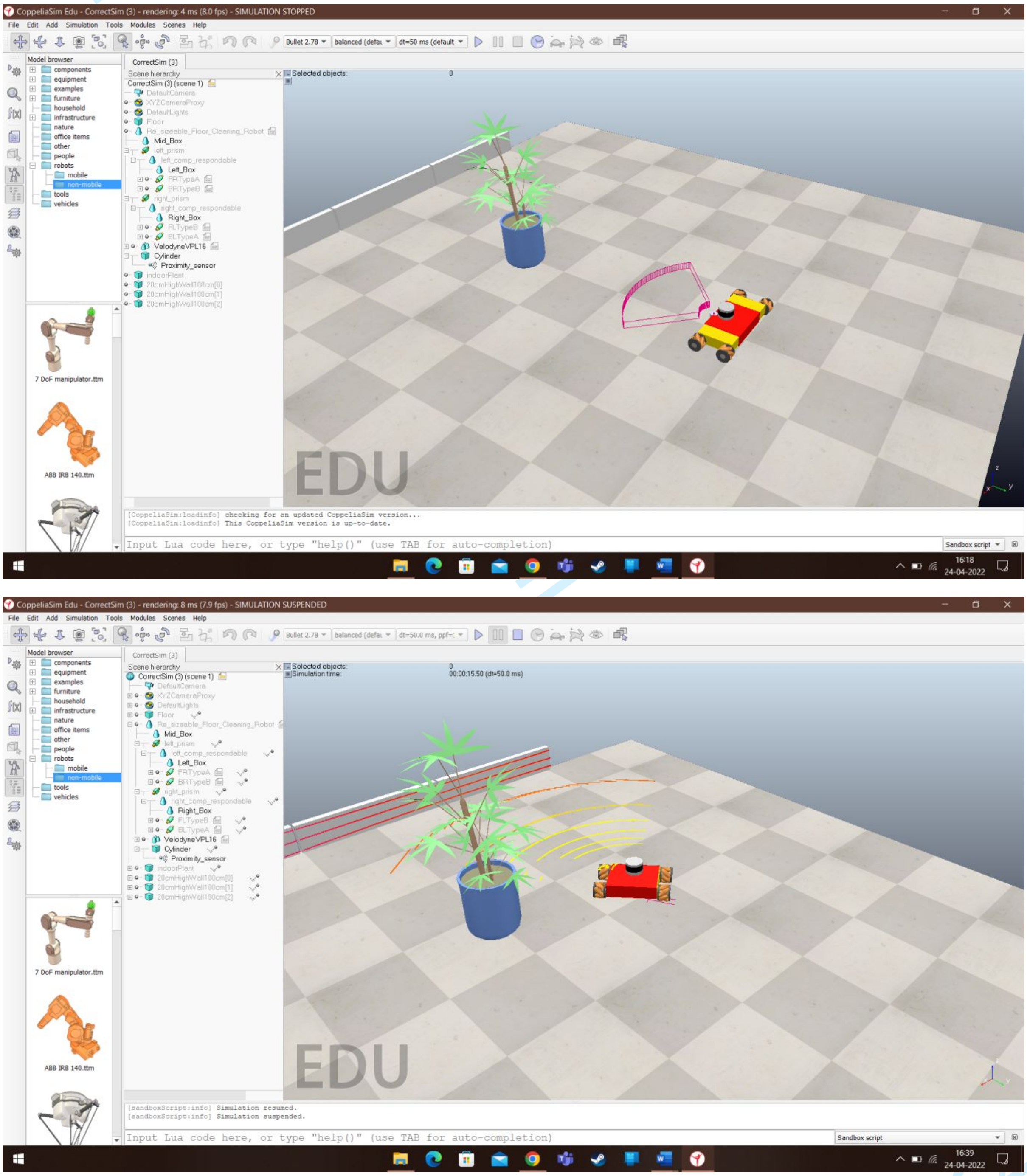

Fig. 12 Simulation

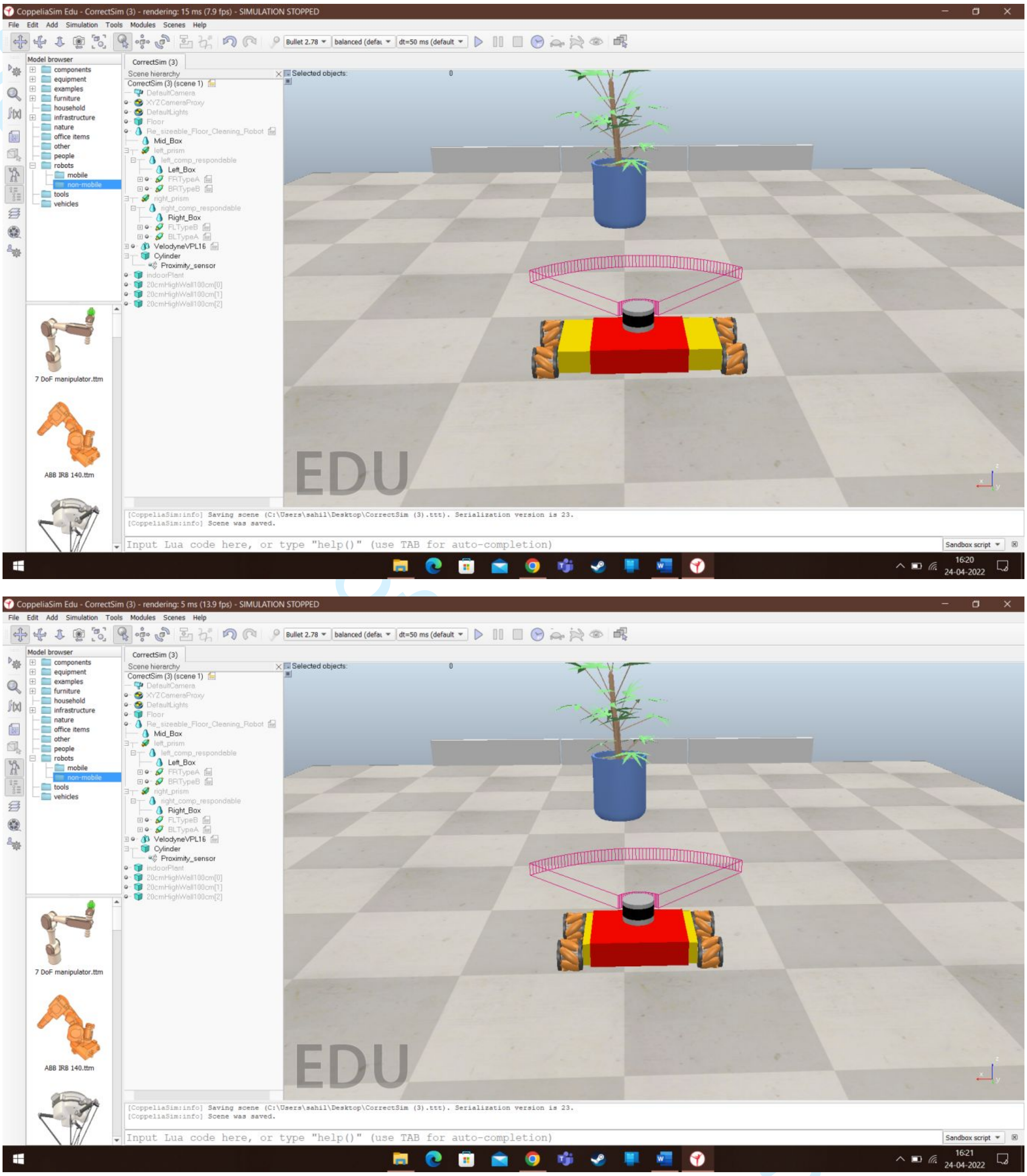

Fig. 13 Length Actuation (Simulation): Fully Extended (Above) and Fully Retracted (Below)

3.3 FUNCTIONAL PROTOTYPE

A functional prototype has been developed as a proof of concept to demonstrate the performance of the system in the real world. The design was modified to simplify the model and reduce costs at the same time, ensuring that the critical components and concepts of the robot are not affected.

The chassis has been designed using Mild Steel sheets. MS sheet was chosen because of its relatively low cost, high strength and easy availability and machinability. Two ultrasonic sensors have been used for obstacle detection.

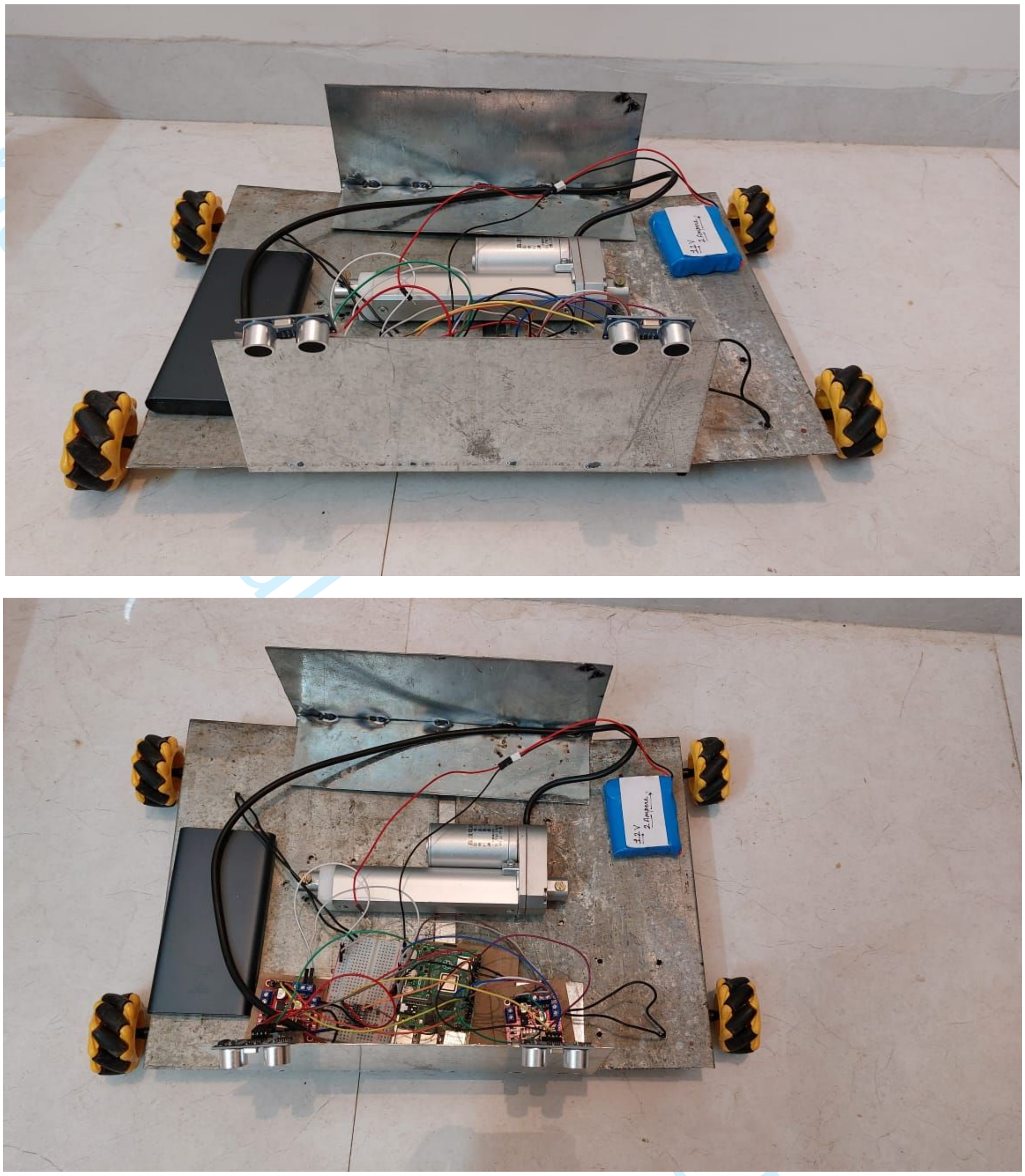

Fig. 14 Functional Prototype (Fully Retracted)

The most challenging aspect has been the design of the chassis for the Functional Prototype. Having chosen sheet metal, the major problem that had arisen involved the bending of the chassis and subsequent loss of traction to the wheels. Choosing a thickness for the sheet involved creating a balance between rigidity and weight. Finally, an MS sheet of 1 mm thickness proved to be satisfactory.

The robot has been developed assuming that standard elements such as LIDAR, Ultrasonic sensors and camera will work as expected and will not be affected by the re-sizing aspect of the robot. Although vacuum calculations have been conducted, it has been completely theoretical. Real life performance may vary, and hence it has been assumed that a vacuum pump of sufficient capacity will function satisfactorily, and will not fail in picking up dust particles despite the increase in the vacuum system orifice.

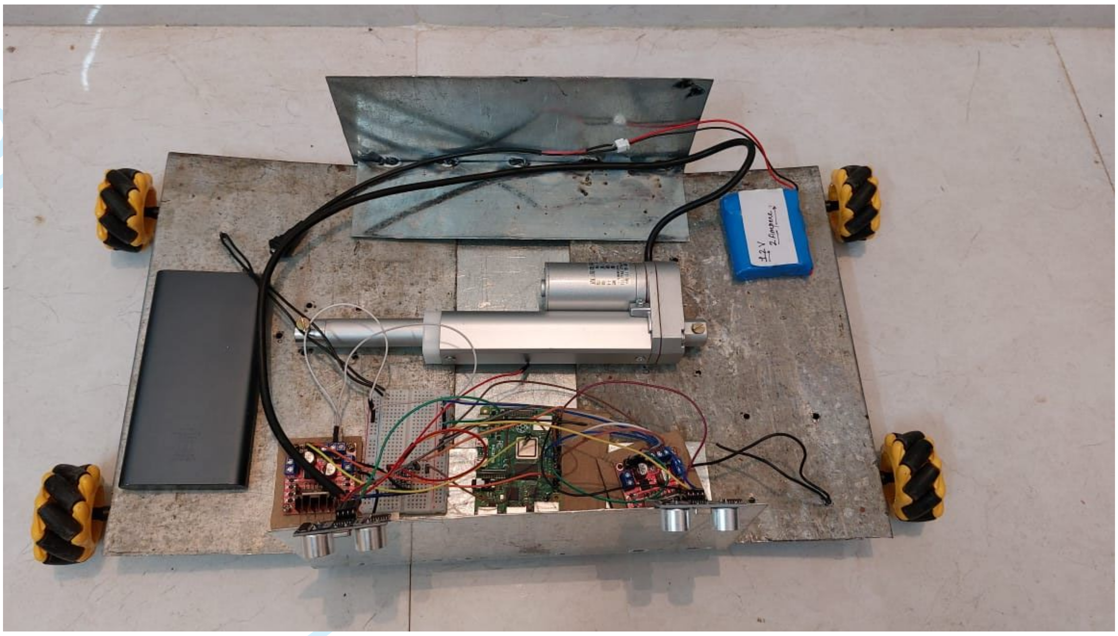

Fig. 15 Functional Prototype (Fully Extended)

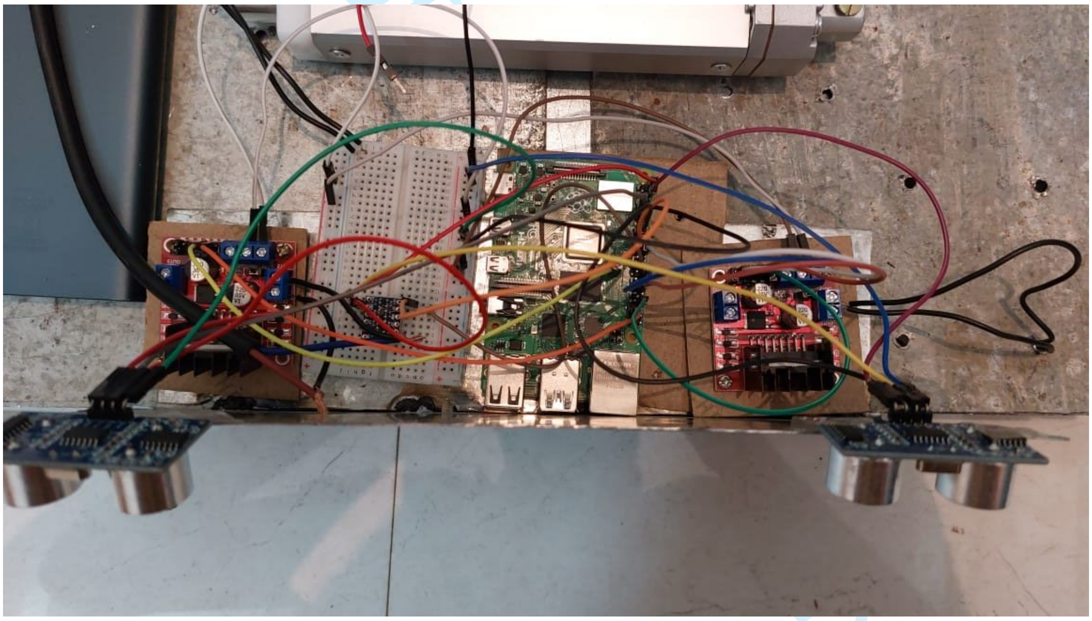

Fig. 16 Functional Prototype (Circuit)

The components include a linear actuator, two motor drivers, four motors and Mecanum Wheels, two Ultrasonic sensors, a Raspberry Pi 4, a bread board, a 5V battery and a 12V battery.

4. CONCLUSION

A simulation study has been demonstrated to verify the efficacy of the system. Further, a functional prototype has been developed as a proof of concept to test the system in the real world. A static stress analysis has been conducted to determine the factor of safety of the chassis, which is the main load bearing element of the robot. Since the chassis is made of MS sheet, the weight of components will introduce stresses and bending. The stress analysis as well as the model developed prove that bending and subsequent failure are not a problem. Future work will involve integrating SLAM using LIDAR, for more efficient and systematic cleaning.

The analysis results show that the Factor of Safety is 15, hence the chassis will not fail. The maximum displacement is 0.3745 mm, which is at the middle box chassis. Further, the maximum stress induced is 14.75 MPa.

A Simulation environment has extremely ideal conditions, and there are no stresses induced on the robot. However, in the real world, there are several factors such as weight of components and friction that affect the performance of the robot. As a result, several iterations were required to attain a chassis that was performing well. Earlier iterations of the functional prototype suffered from bending of the chassis and loss of traction to the wheels. Having identified the problem areas, necessary modifications were made to the chassis to ensure compliance. After several iterations, a chassis was finally developed that functioned well. Such complications are not faced in a Simulation study, hence developing a functional prototype is of utmost importance, and has its own set of challenges.

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