Milestone 3

Group Project Team 03

Faculty of Technology and Bionics

The Self-Navigating Autonomous Robotic Cutter SNARC

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Acknowledgment

This project is solely completed by the listed group members under the guidance of the project supervisors. All the information taken from the internet and other resources has been cited and accounted for. If there is any resemblance to other similar projects, it is purely by coincidence. We'd like to thank the supervisors and authors of the referred articles and reports for their contributions to the project.

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Executive Summary

Recently, the market for service robots has been expanding, more specifically in the domestic use field. This proves useful with regards to the German demographic which is shifting towards an increasing elderly population. The Self-Navigating Autonomous Robotic Cutter (SNARC) aims to cut grass between cobblestones for domestic environments to maintain patios. It is equipped with a Pi Camera module V2 with a protective hood for maintainability and better performance in rainy weather as well as sensors for safety, border detection, and performance purposes. The rain sensor and Pi Camera detect if the vision is hindered due to rain, and a message is sent to the LCD for the user to clean the lens for further operation. The inputs from the environment are connected to a data bus in a master-slave configuration, and those input signals then undergo conditioning to remove unnecessary noise and amplify the signal before analog-to-digital conversion (ADC) and further processing by the Raspberry Pi.

The computer vision aspect will be done using Open Source Computer Vision Library (openCV) on python, the input undergoes steps like noise reduction and edge detection that enable it to distinguish the different surroundings. SNARC uses a 12V battery that is connected to the components in parallel, and DC-DC step-down converters are then used to provide the required voltage for each component. SNARC uses a DC motor for the cutting mechanism and another DC motor for the cleaning mechanism and four DC motors for the mecanum wheels. Since the robot is meant for domestic use, a nylon line trimmer is used to grant safe use. The use of mecanum wheels allows for more flexibility of movement during operation.

The pseudo code of the system was included to show the sequential order of command execution during operation as well as how SNARC responds to interrupts from external events. The electrical and mechanical parts were also shown in the bill of the materials along with their prices. After cost calculations and production planning it was shown that the target volume can be achieved while making a profit.

Keywords:
Self-navigating, real-time, computer vision, openCV, mecanum wheels, Raspberry Pi

Contents

Introduction

As more products are being automated for the convenience of consumers, service robots development is becoming more prominent in the market with international companies like the American iRobot corporation contributing to such product development. Aimed at the same market, SNARC provides a solution for ingrown grass between cobblestones for domestic households. With the help of sensors and image processing, it works autonomously. The following components are integral to the functionality of the robot and are chosen to maximize contribution to the design, economical aspects, safety, and robustness.

It is important to note that the following paper discusses the main components only, as it is understood a machine like this has many smaller components and connections not explicitly mentioned for the purpose of simplicity.

List of Main Components

Raspberry Pi:

The microprocessor used is Raspberry Pi due to its image processing capabilities. Even though other smaller microcontrollers have the I/O and computing capabilities, it is the image processing aspect of Raspberry Pi that makes it suitable to take in input data from the camera for further processing. The Pi Camera module V2 and openCV Python library are to be used with the microprocessor for the computer vision aspect [2]. The processing of the input from the camera will enable the identification of obstacles and path of motion with the aid of sensors in order to send commands to the motor controllers and in turn the mecanum wheels with the direction they should move in. The Raspberry Pi will be used for the prototype for the analysis of the robot. For the manufacturing, further investigation will be carried out to see products that would cost less for mass production of the robot as well as perform risk assessment about its performance to avoid data overflows and provide appropriate memory space.

Pi Camera Module V2:

The camera provides the visual input to the system. It looks for distinctive features and objects and analyses them, and with other inputs from odometry and gyroscope sensors, the robot is able to localize itself and know where it is in relation to the environment. The Pi camera presents an important advantage, since it is directly connected to the Raspberry Pi board's Graphical Processing Unit or GPU, therefore, offering enhanced performance for a lower cost [7]. The camera used is module V2 and it supports various video resolutions like

1080p30 and 720p60 [17]. To use the camera, the camera interface needs to be enabled on the Raspberry Pi software configurations, or by using the following command in the Terminal:

`pi@raspberry:~ $` **`sudo raspi-config`** [17].

The camera lens will be covered with a hood that would protect it from the rain, but when the lens does get wet and the visibility is decreased, then the user gets a notification on the screen to clean the lens.

Computer Vision using Python's openCV:

For the image processing, Python openCV is used to apply algorithms to the visual input from the camera. The input undergoes a series of steps in order to filter out the most relevant information from the environment. These steps include converting the image to grayscale and applying a bilateral filter whose purpose is to remove the background noise while maintaining the edges in the visual input [20]. This allows for further processing and analysis of the color gradients of the pixels to see where edges occur in a process of canny edge detection [19]. The contours are then determined, and the surrounding objects and obstacles are detected and identified. To use the camera, it first needs to be imported using the *import picamera* command. The video resolution is then to be determined in the code and the recording is done through the command: <cameraName>.start_recording(<nameString>) [17]. When the robot is turned off, it is commanded to stop recording. The computer vision aspect is not the sole source for localization of the robot and obstacle detection, as an array of sensors are also used for this function for an enhanced overall performance.

Battery :

Seeing as there are various autonomous home maintenance robots already on the market, such as robot vacuums and lawn mowers, a reasonable conclusion is that customers already have an expectation on how long a robot lasts before it needs to be recharged. Accordingly, as a new organization looking to enter an ever changing autonomous robot market, it is necessary to meet those expectations. Some of those expectations that SNARC aims to fulfill are:

- Being able to navigate and cut around the whole space on a single charge.
- Recharge does not take long durations of time.
- Autonomous and self recharge capability without human intervention.
- Operation time of 30 minutes.

It is clear that technical data such as maximum output current and maximum voltage are the defining factors along with the weight and placement of the battery in the system. It is also necessary that the battery used is rechargeable via the charging pad to retain autonomy.

Sensors:

Sensors take in mechanical data and convert it into electrical data for the microcontroller to process and make appropriate decisions. Consequently, the sensors used in SNARC are used for two main reasons: obstacle detection and orientative purposes. Not all sensors are mentioned in the text, so the list of sensors include, but is not limited to:

Wheel Odometry sensor:

Odometry is the use of motion sensors to determine the robot's change in position relative to some known position. It is possible for the robot to know how far it has traveled by determining the number of wheel rotations. Combined with the data from image processing, this is an important addition to aid robot positioning. [16] Since the mecanum wheels are omni-directional, and sideways movement would go undetected by the odometer, the vision system will be taking charge with the help of the depth sensing camera module used.

Gyroscope sensor:

This sensor is used to measure relative angular change of rotation. In SNARC, it would help the robot in laterally orienting itself in the environment for further accuracy in positioning.

Incline sensor:

Incline sensors measure the angle of incline relative to the gravity on Earth. It can detect a sudden change of height as well, so if the machine is picked up, stuck on its side, or perpendicular to the ground where the cutter is shown, a signal will have already been transmitted to the DC motor to be turned off.

Cliff sensor:

A cliff sensor is rather for the safety of the machine than anything else. They simply measure the distance of the robot from the floor by bouncing IR light and calculating the time it takes for it to return, if this has suddenly increased, it is apparent to the machine that it's approaching a drop or stairs. For this reason it's essential to have these sensors not only on the front of the robot but also on the sides.

Object sensor:

Object sensors enable the robot to turn around or find an alternative path on its route if the front bumpers encounter any obstacles. These sensors are sort of a 'last resort' sensor because it is favorable to not have to use them to minimize damage to the robot since they need to have direct contact with the obstacles to function. Wall sensors are used additionally to avoid ever having direct hard contact with the machine with the aid of the vision system.

Hall effect sensor:

To make sure that the robot does not overstep the boundaries within it should clean, a magnetic strip may be used along places the robot is not to trespass. Using the principles of electromagnetism, the voltage changes proportional to a present magnetic field. This voltage change is caused by the change in the current flow within the semiconductor due to the presence of a permanent magnet [1]. This magnetic field detection by the Hall-Effect sensor is used to keep the robot operating within boundaries [21].

Rain sensor:

Rain is not an ideal environment for a robotic weed remover to function. The terrain changes considerably and in heavy rain it can smudge certain parts of the robot, the user interface and camera to name a few. The protective hood on the camera lens is to protect it from some levels of rain, but when it reaches the level of obscuring the vision, the robot stops the cutting mechanism and starts searching for its charging pad. It will have to be manually restarted again from the charging pad once the climate is appropriate for its use.

It is now apparent that sensors are key components of SNARC and one of the pivotal technological developments that not only allow it to locate itself but also react to some anticipated triggers based on predefined behavioral conditions.

Mecanum wheels:

These wheels have rollers attached to the circumference of the wheel. The rollers are diagonal to the axis of rotation of the wheel.[2] This allows for the movement of the robot to be omnidirectional controlled by the DC motor. This is particularly useful for a mobile robot that has to find its own way. It will quite often encounter obstacles or find itself in positions where it has to reverse laterally or move sideways and these movements would otherwise be complicated to perform. The following figure sums up various movements an autonomous robot can be expected to make with mecanum wheels.

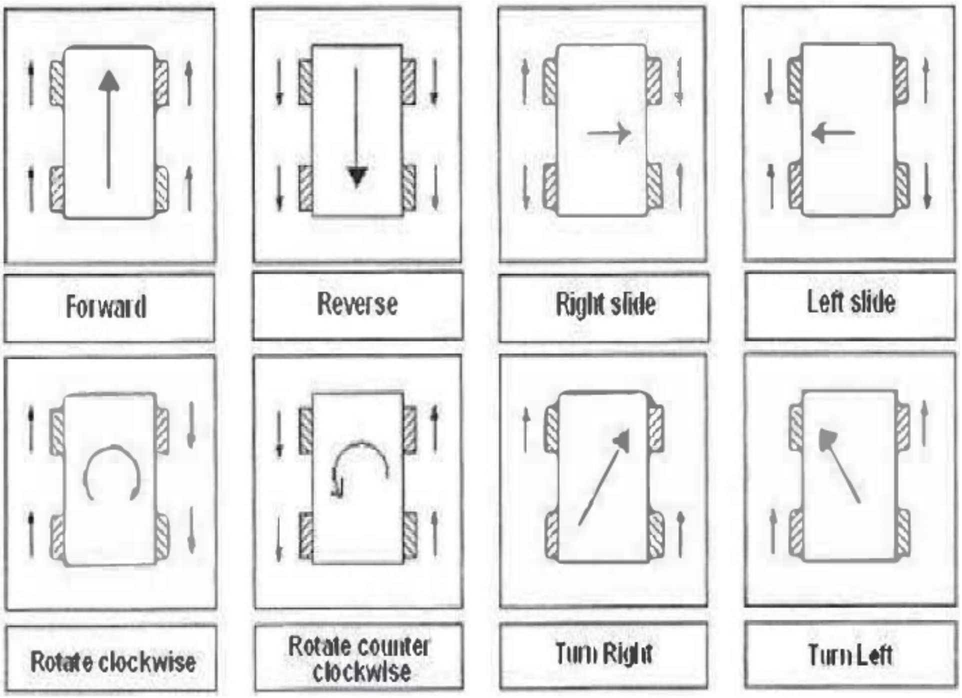


Figure 2.

Figure 1: Indicates the direction of the robot's movement based on the commands for the movement of each wheel from the DC motor. [19]

The LCD and User-Interface:

The user interface consists simply of two push buttons and a LCD display which allows the display of error messages and important information to the user like the current time and the amount of charge left in the battery. The two buttons are the power button and the dock button. For the dock button, the robot acts according to the same protocol as it would when prompted by low battery or a finished job and would try to find its charging pad. The power button switches on or off SNARC.

DC Motor and motor controller:

A large torque, high RPM and low noise DC motor is suitable here. This motor will be connected to the cutting mechanism. The speed of the motor is again controlled by pulse width modulation via the Raspberry Pi and a motor controller connected that provides the required current at the appropriate voltage. This would be connected as an open loop system since feedback from the motor itself is not necessary.

In the concept design phase, servo motors were used for the mecanum wheels, however, that was changed due to the fact that servo motors can only do 180° rotations. As well as factors like DC motors weighing, and costing less for the same amount of torque produced. This change means that the additional 4 DC motors for the wheels will have to be controlled by 2 additional dual motor controllers. It's specifications are outlined in the requirements manual section.

Choices of Cutting Mechanisms

An evaluation of various different cutting mechanisms was performed. The initial idea was to use microwaves to kill the weeds. It was considered a waste of energy since a cutting mechanism would be required regardless. There would also be safety considerations like cooling the stone ground after heating it up to high temperatures.

Other alternatives considered were weed torchers, with either fire or light [14]. It was found that in most cases, along with wilting the plant, the high heating mechanism also uproots it. After further research it was concluded that it was not feasible because the killing and removal of every individual plant would take a long time and the head of the robot would have to be angled different ways onto the plant for proper removal. This would have complicated the hardware design and added further mechanical complexities. For this reason, this idea was discarded.

Finally, after much further research it was decided that the nylon line trimmer would be used as a cutting mechanism. The technology already exists and is already being used on cobblestones to remove overgrown weed. [8] The motors connected to these lines can generate enough torque to successfully cut the weed while also not damaging the cobblestones themselves. They can be used on stony sections and close to walls as nylon lines do not get damaged as easily as plastic for example. [5]

It can also be replaced when close to wear and tear, additional lines would be provided alongside with a manual of how to replace in case it happens to erode. From a safety point of view, the risk of injury and damage from a spinning nylon line is far less than a spinning metal blade for example. The nylon trimmer line also uses a torque of 3.4 Nm as compared to 19Nm for metal blades for the cutting mechanism [8]. And from an economical point of view, nylon lines are cheaper and lighter than metal blades [5].

In conclusion, after much research and debates on which cutting mechanism to use in the robot, it was unanimously agreed upon that the nylon line cutter was the most suitable and in line with the goals of SNARC.

Charging Pad

When low battery level is detected, SNARC starts navigating back to its charging pad, where it self-docks and starts recharging. The hardware components of the charging station include a charging module, a current detection module, an infrared transmitter, and electrodes. In the concept design phase, a mechanical shutter was incorporated into the charging pad. However, since this would add more moving parts that do not contribute to the main function, the maintenance that would come with it on the user end would be unnecessary. Therefore, for user convenience, it is decided to not carry it forward in the design. Instead a cover is used to provide the same protection for the robot while charging.

To navigate back to the charging station, the robot uses its own localization techniques to find the charging base. It knows where it has started from so even if the infrared rays from the charging pad are not visible to the robot, it can go sufficiently close to it because it has built a map of the area. Once in the docking area, infrared detectors on the robot's body allow it to approach and align itself with the electrodes on the station.

For it to electrically dock, the electrodes have to touch the contacts on the robot for the current to pass through and recharge the battery.

IR sensors are often said to be placed in locations where there is less sunlight since the rays of the sun can manipulate readings. However, if the IR LED is pulsed on and off with a high frequency, it is detectable with an IR sensor with high pass filters. So therefore, the charging pad can definitely be placed in an outdoor location.

3D Sketch and Design Decisions

The following concept model, meant to serve as an outline of the general shape that the robot will take, was developed further for the product design phase to enhance the function and the appearance of the robot.

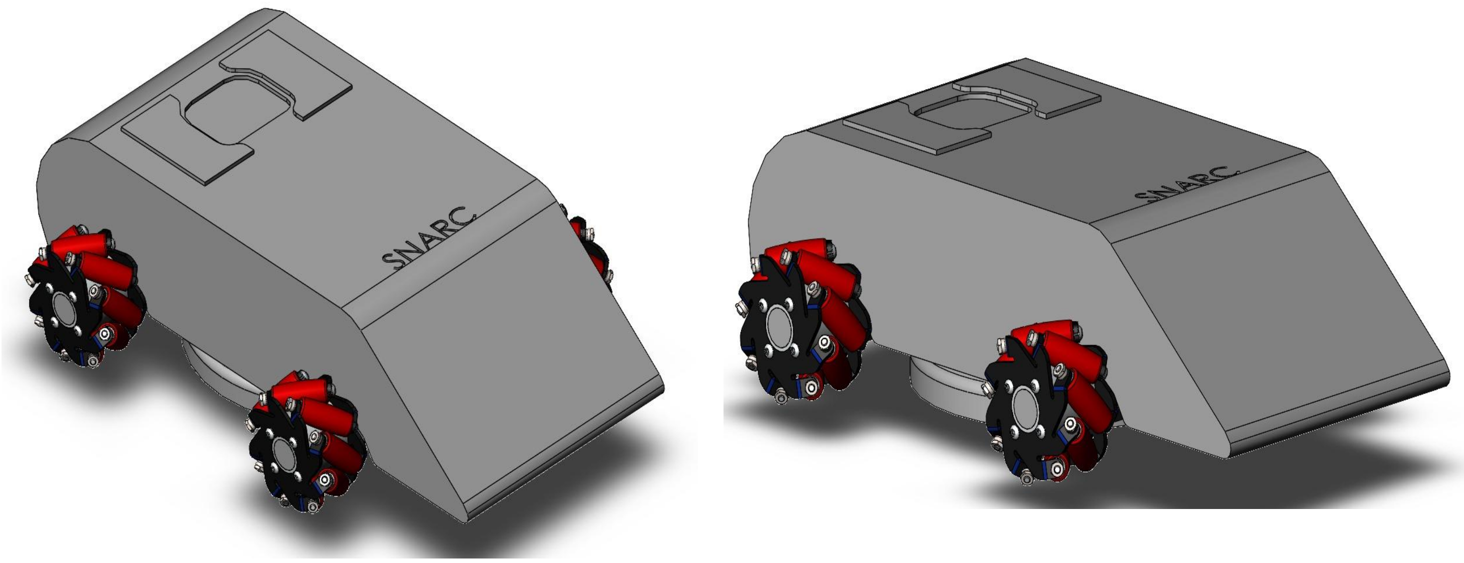


Figure 2. CAD model of SNARC

The figure below shows the updated CAD model of the robot, where the shafts for the wheels, vacuum, as well as slots for the motors controlling the wheels have been added. The slots for the motor also have vents to decrease the risk of overheating.

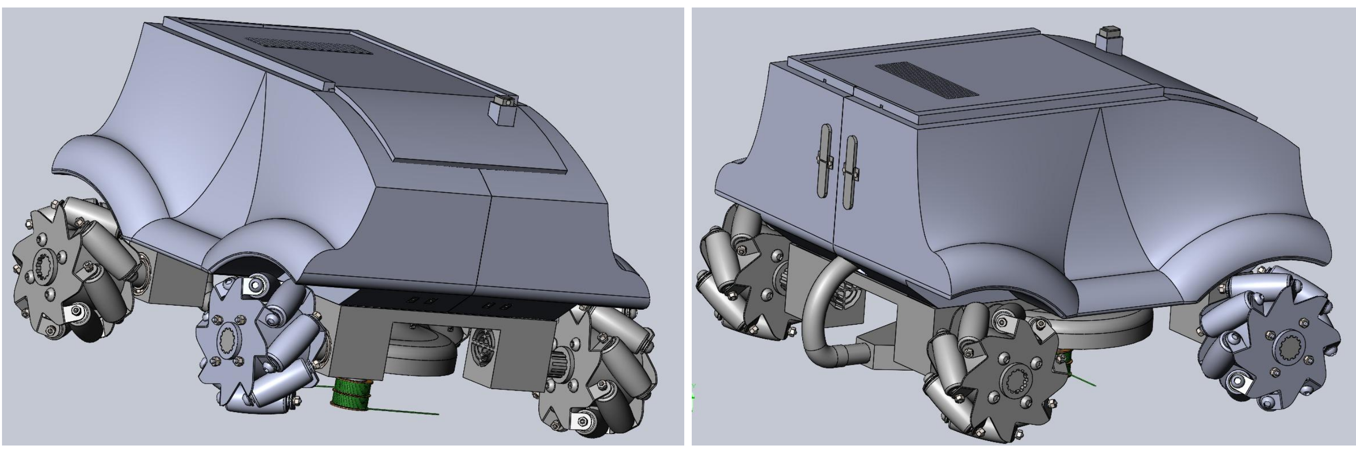


Figure 3. Updated 3D CAD Model.

The first noticeable aspect of the model is the mecanum wheels that help maneuver the robot around smoothly. Future renditions of the model could possibly show a more streamlined fitting for aesthetic purposes.
The cutting mechanism is also visible underneath the robot surrounded by a protective cover, it is meant to stay just above the ground so even smaller plants can be precisely removed for optimal cobblestone cleaning.
Finally, on the top of the robot, the LCD screen displaying charge and time is surrounded by two big pushbuttons.

Market Decisions

Introduction

The most essential parts of SNARC are the parts that make it different from typical domestic weed removal solutions. The cutting mechanism itself is based on safe and light nylon lines and is suited for quick removal. Its autonomous capabilities allow it to navigate a home-owner’s porch and dock itself back when it has finished its job, all while making sure your dog does not get in the way. SNARC is here to redefine external house maintenance, without burdening the home-owner with back pain and the mundane task of weed removal.

By reducing operator fatigue, equipment design is slowly moving towards more ergonomic solutions. This is a specially helpful edge to have in the German market. The German population pyramid and its future models show the stark reality that the population of Germany is set to get older.

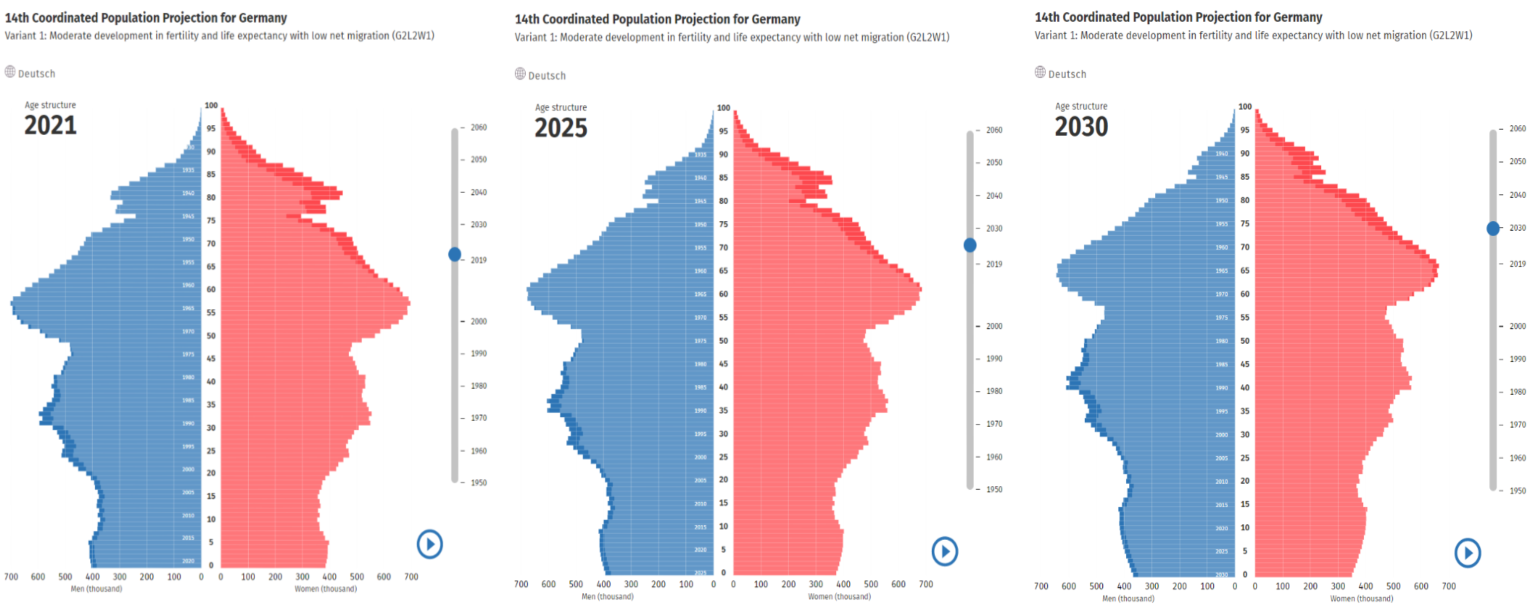


Figure 4. Population projection for Germany [10]

To be marketed as autonomous and self-docking, effectively a solution to hard manual labor, it gives SNARC an edge in the aging market in comparison with its manually operated competitors. The following sections outline further analysis of the market size and planned sales volume.

Mission Statement

SNARC is built to revolutionize home maintenance.
The main aim is to foray towards automation of patio conservation techniques while capturing a significant market share of this industry.

The ultimate goal is to improve the quality of life of home-owners across Germany and to participate in the inevitable and exciting future of smart robots.

Situation Analysis

Product/Service	Robotic Cobble Cleaner.
Unique Selling Proposition	The robot is an autonomous, self-navigating, electric machine that can recharge itself automatically when hitting a critical battery level.
Marketing Objectives and Performance	Penetrating the household European market by introducing a high quality, moderated price product.
Challenges	Introduction of a new complex technology with a lot of new factors and options.
Competitor Analysis	Not many competitors who are selling a high-quality product for a reasonable price in addition to the disadvantage of it being manually operated by an experienced operator.

SWOT Analysis	
Strengths	**Weaknesses**
- Operating in Germany allows for hiring of highly skilled workers and engineers. - Futuristic design and features like self-charging and autonomous navigation.	- Relatively no experience in the market. - New brand could be worrisome for some customers. - Economy of scale is not beneficial to SNARC in the first year due to low market share.
Opportunities	**Threats**
- Market expansion by 5 % in the year 2025. [87] - Social media promotion and advertising. - Spike in e-commerce due to the Covid-19 pandemic. - Rise in fuel price and global warming means that electric powered products are in demand.	- Convincing customers to purchase a new product. - Electric powered machines are attracting more entrepreneurs which means more competitors. -Well known brands releasing their own autonomous products for this market.

Target Market

Landscaping in the German region through a market mix between: Online campaigns and promotions via social media, a penetrating price strategy, and a high-quality electric product. Households from middle and rich classes who live in private houses are the main target segment. Household net income per month starts from 2000 €.

Pricing Strategy

Which pricing strategy is suitable?

Base It on Costs	**Base It on Competitors**	**Skim It**	**Penetrate It**	**Bundle It**

Why this pricing strategy?

Rapid spread of brand, faster customer attraction, and penetrating the already established market.

What will be the price of the product?

Product/Service	Price
SNARC	499 € - 799 €

<u>Range 499 € - 799 € for one unit depends on the supply & Demand principle:</u>

A lawn mower product was used as a benchmark for the search because it had the most similar technology and market as SNARC does. By web scraping the prices from Amazon.com, prices starting from 370€ till 1,999€ approximately were found to be the range for that product. Consequently, It showed that the range between 499€ and 799€ would be the moderate range and the price should fall in between. This is how the price of the product was decided. However, taking the final pricing decision will depend on the cost calculations of the various components in use and hardware considerations.

```
Collecting bs4
  Downloading bs4-0.0.1.tar.gz (1.1 kB)
Requirement already satisfied: requests in c:\users\mahmoud\anaconda3\lib\site-packages (from autoscraper) (2.24.0)
Requirement already satisfied: beautifulsoup4 in c:\users\mahmoud\anaconda3\lib\site-packages (from bs4->autoscraper) (4.9.1)
Collecting urllib3!=1.25.0,!=1.25.1,<1.26,>=1.21.1
  Downloading urllib3-1.25.11-py2.py3-none-any.whl (127 kB)
Requirement already satisfied: idna<3,>=2.5 in c:\users\mahmoud\anaconda3\lib\site-packages (from requests->autoscraper) (2.10)
Requirement already satisfied: chardet<4,>=3.0.2 in c:\users\mahmoud\anaconda3\lib\site-packages (from requests->autoscraper)
(3.0.4)
Requirement already satisfied: certifi>=2017.4.17 in c:\users\mahmoud\anaconda3\lib\site-packages (from requests->autoscraper)
(2020.6.20)
Requirement already satisfied: soupsieve>1.2 in c:\users\mahmoud\anaconda3\lib\site-packages (from beautifulsoup4->bs4->autoscr
aper) (2.0.1)
Building wheels for collected packages: bs4
  Building wheel for bs4 (setup.py): started
  Building wheel for bs4 (setup.py): finished with status 'done'
  Created wheel for bs4: filename=bs4-0.0.1-py3-none-any.whl size=1279 sha256=32dd79448416309e64f18a6a9da8b48469452b28f1e49c3ff
50ee9fafca9880b
  Stored in directory: c:\users\mahmoud\appdata\local\pip\cache\wheels\75\78\21\68b124549c9bdc94f822c02fb9aa3578a669843f9767776
bca
Successfully built bs4
Installing collected packages: bs4, autoscraper, urllib3
  Attempting uninstall: urllib3
    Found existing installation: urllib3 1.26.7
    Uninstalling urllib3-1.26.7:
      Successfully uninstalled urllib3-1.26.7
Successfully installed autoscraper-1.1.12 bs4-0.0.1 urllib3-1.25.11

In [9]: from autoscraper import AutoScraper

In [31]: url = 'https://www.amazon.co.uk/s?k=robotic+lawnmower'
         wanted_list = ['£699.99  ', 'Hyundai Robot Lawnmower 625m² Lawns, Self Charging, Mulching Robot Mower, 2 year Warranty, 22.2V - 2

In [32]: scraper = AutoScraper()
         result = scraper.build(url, wanted_list)
         print(result)

['£368.88', '£399.99', '£699.99', '£569.99', '£1,999.99', '£446.06', '£499.99', '£559.99', '£649.99', '£349.99', '£629.00', '£6
83.76', '£729.99', '£749.99', '£684.22', '£749.97', '£839.99', '£495.01', '£529.98', '£476.12', '£429.99', 'Hyundai Robot Lawnm
ower 625m2 Lawns, Self Charging, Mulching Robot Mower, 2 year Warranty, 22.2V - 2.0Ah Lithium-Ion Battery, Ultra quiet, 25-55cm
Cutting Height, HYRM1000, Blue']
```

Figure 5. The code for the Amazon web scraper

written by Mahmoud Attia

Distribution Strategy

The product will be supplied through a mixed channel policy between direct and indirect channels. Direct channels through specialized distributors and big retailers. Indirect channels through a specialized online platform.

Promotion Strategies

- Targeting Blogs
- Search Engine Marketing
- Social and Display Ads
- Search Engine Optimization
- Email Marketing
- Sales
- Existing Platforms
- Trade Shows
- Speaking Engagements
- Community Building

Market Size & Planned Volume

According to the Federal statistical office, the number of dwellings is 42.8 million in Germany by the end of 2020 [9]. For the first year, the targeted households are households with a net income more than or equal to 2000€ per month.

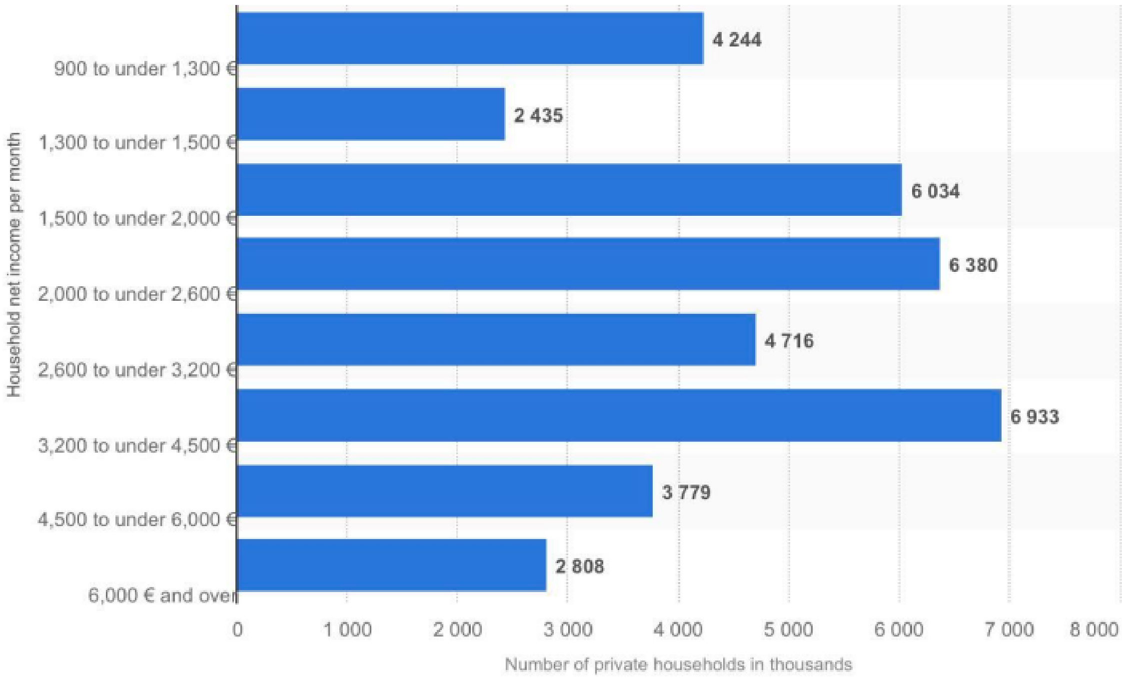


Figure 6. Private household income distribution in Germany 2019 [11]

Based on the statistical chart shown above, the customers that can afford the product in general are more than 20 million. The product re-buying cycle is about 3.5 years on average.

Since there is no market for autonomous cobble cleaners, it's reasonable to view robotic lawn mowers as a similar market. Europe is the second-leading market for robotic lawn sales and is expected to grow at 11.7% CAGR in coming years. [13]

In the first year only the domestic market is targeted.

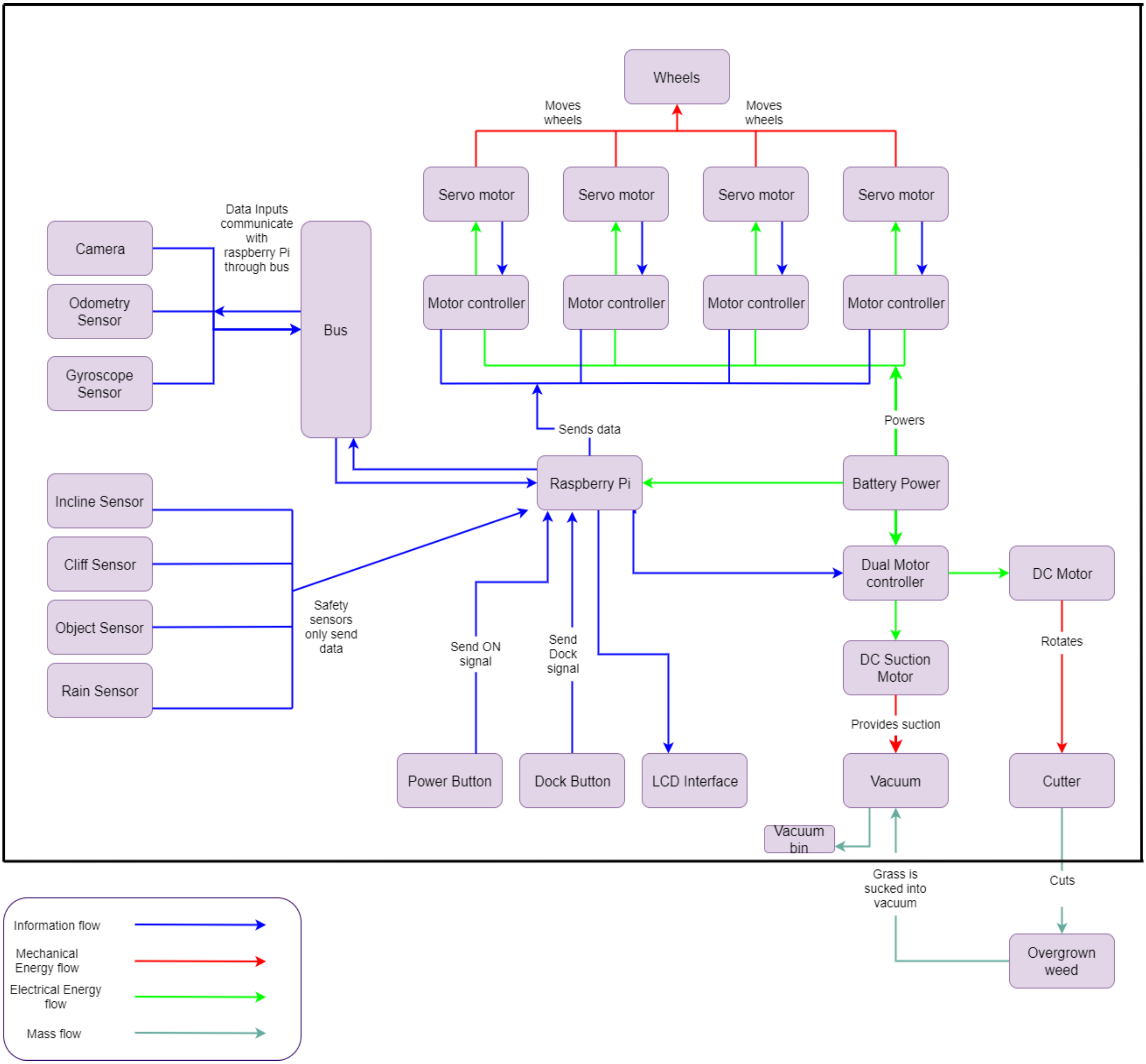
It is possible to sell an average of 12500 units per month or 150000 in the first year. So, the initial target for planned sales is to reach approximately 7.5 million euros as annual revenue.

D-FMEA

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity	Cause of Failure	Occurrence	Detection	RPN	Responsibility	Actions taken	Results of Actions taken			
											Severity	Occurrence	Detection	RPN
DC Motor	Rotation of the nylon blades	Lack of electric current	No rotation in the cutting blades	6	Damage in the wires	2	3	36	Pratyush Sharma Moiz Uddin	A simulation of electric circuit is preformed, and the wire connections are made in such a way that reduces the possibilities of such incidents.	6	1	1	6
Servo Motors	Rotation of the wheels	Lack of electric current	No rotation of the tires	5	Damage in the wiring system	2	4	40	Farah Kamal Syed Talha	A simulation of electric circuit is preformed, and the wire connections are made in such a way that reduces the possibilities of such incidents.	5	1	1	5
		Gear might be broken	Wheels unable to receive the torque	5	Improper knowledge of mechanical connections	2	2	20		Improved gear connections and better calculations of torque and force to decrease the chances of this happening	5	1	2	10
Camera/ Vision System	Detection of the grass, mapping of the environment, object detection.	Failure to identify the grass	The blades running over the bricks and cobblestones and decreasing efficiency.	6	Blurry camera	5	4	120	Farah Kamal Syed Talha	The program of the sensor has been improvised so that it can detect grass even if the visibility is not good.	6	1	1	6
		Lack of sight or unable to send visual data to the processor	Unable to provide the visual data input to the processor, misdirection, can't find charging dock.	9	Some kind of blockage in the view of the camera	6	1	54		Providing a glass sheet in front of the camera that can be removed and cleaned manually to provide constant visibility	9	3	1	27
Position sensors	Navigates the path of the cutter and provides the information about the current location of the cutter	Inability to navigate or unable to send the location of the device to the main processor	The device will not be able to locate itself and locate the rest of the area to operate on	8	Physical damage to the sensor.	3	2	48	Moiz Uddin Pratyush Sharma	The position sensors are placed on the inside of the machine where the possibilities of damage decrease significantly, and the sensor is also safe from rain water or dust.	8	2	1	16
		able to provide the required amount of power supply	our circuit		of power distribution in the circuit					the purpose of our project				
Battery	To provide requisite power supply to our circuit	Battery leakage	Leads to faster drainage of battery, leakage will also cause damage to the battery case	7	Not replacing the battery when it is fully discharged, or even mixing up the batteries	3	8	168		A battery condition monitor is installed inside the device that shares the condition of the battery with the main processor and in case of any slight leakage the user is informed.	7	2	1	14
Electrical Wiring	To provide the electrical connections as well as provide the signals to the main processor	Wires get disconnected or loose	Loss of signal transmission to our required connection	6	Human error or loose connections	5	3	90	Syed Talha	A simulation of electric circuit is preformed, and the wire connections are made in such a way that reduces the possibilities of such incidents.	6	1	3	18
		Shot circuit	Maximum it can burn our circuit	8	Faulty wire connections or maybe ageing of the wire	4	4	128		A better understanding of the schematics of the electric circuit can help prevent this from happening	8	1	4	32
Blades	To cut the weed between the cobblestones	Damaged caused by friction that takes place while cutting the blades	The blades are not in a condition to cut the grass	3	Ageing of the blade and constant damage by friction	5	2	30	Mahmoud	The user is guided about the wear and tear occurring on the blades and also the recommended time period of the blades is calculated and informed to the customer in the user manual.	3	3	1	9
Wheels	Makes machine capable of mobilizing	Wheel could pop out loose	The device might not be able to move	10	A Poor nut connection	3	2	60	Pratyush Sharma	The joints between the wheel and the shaft are frequently examined during the design phase.	10	1	1	10
Vacuum System	Collects debris from the ground	Pressure leak in the suction tube	Unable to lift the debris from the ground	9	A hole torn in the suction tube	5	3	135	Moiz Uddin	A thicker insulation is placed on top of the suction tube and a metal grill is used to protect the suction tube from sharp debris	9	2	2	36
Raspberry Pi	Provides processing capabilities to the robot, take several inputs to send instructions to the motors	Not able to process information. Becomes slow and	The robot doesn't work as intended, doesn't avoid dangers, becomes more dangerous to be around, navigation stops working.	10	Overload of information from many different inputs	4	4	160	Farah Kamal	A bus can be used between the sensors and Raspberry Pi, where it can take information one by one	10	2	3	60

Functional Structure

In the concept design phase, a data bus was used for taking inputs from the environment, and in the product design phase, it is specified that an I^2C data bus is used.



GANTT Chart

Project Name	Start Date	End Date
SNARC	05.10.2021	17.01.2021

Taks ID	Task Description	Start Date	End Date	05-Oct-21	06-Oct-21	07-Oct-21	08-Oct-21	09-Oct-21	10-Oct-21	11-Oct-21	12-Oct-21	13-Oct-21	14-Oct-21	15-Oct-21	16-Oct-21	17-Oct-21	18-Oct-21	19-Oct-21	20-Oct-21	21-Oct-21	22-Oct-21	23-Oct-21	24-Oct-21	25-Oct-21	26-Oct-21	27-Oct-21	28-Oct-21	29-Oct-21	30-Oct-21	31-Oct-21
1	**Concept Design**	**05-Oct-21**	**02-Nov-21**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
1.01	Fabrication of work packages	05-Oct-21	06-Oct-21	X	X																									
1.02	Allocation of Responsibility	06-Oct-21	07-Oct-21		X	X																								
1.03	Development of GANTT Chart	07-Oct-21	09-Oct-21			X	X	X																						
1.04	Praparation of an initial sketch of SNARC	09-Oct-21	15-Oct-21					X	X	X	X	X	X	X																
1.05	Writing the Product description and executive Summary	10-Oct-21	17-Oct-21						X	X	X	X	X	X	X	X														
1.06	Evaluation of Market Size	12-Oct-21	18-Oct-21								X	X	X	X	X	X	X													
1.07	Price Prediction	18-Oct-21	21-Oct-21														X	X	X	X										
1.08	Planning of the sales volume	20-Oct-21	23-Oct-21																X	X	X	X								
1.09	List of main components	15-Oct-21	20-Oct-21											X	X	X	X	X	X											
1.10	Preparation of Functional Structure	20-Oct-21	25-Oct-21																X	X	X	X	X	X						
1.11	Performing D-FMEA	26-Oct-21	01-Nov-21																						X	X	X	X	X	X
2	**Product Design**	**03-Nov-21**	**30-Nov-21**																											
2.01	Circuit Diagram Creation	03-Nov-21	08-Nov-21																											
2.02	Designing the 3D CAD Model	05-Nov-21	11-Nov-21																											
2.03	Creation of Activity Diagram	08-Nov-21	14-Nov-21																											
2.04	Creation of State Machine Diagram	11-Nov-21	17-Nov-21																											
2.05	Taking 'Make' or 'Buy' decisions	15-Nov-21	17-Nov-21																											
2.06	Technology Selection for 'Make' parts	17-Nov-21	28-Nov-21																											
2.07	Listing down the requirements for 'Buy' parts	17-Nov-21	29-Nov-21																											
3	**Project Documentation**	**01-Dec-21**	**11-Jan-22**																											
3.01	Drafting the Technical Drawings	01-Dec-21	07-Dec-21																											
3.02	Prepararing the bill of material (Electrical)	07-Dec-21	12-Dec-21																											
3.03	Preparaing the bill of material (Mechanical)	07-Dec-21	14-Dec-21																											
3.04	Writing Pseudo Code	13-Dec-21	23-Dec-21																											
3.05	Production Planning	22-Dec-21	30-Dec-21																											
3.06	Cost Calculation	31-Dec-21	09-Jan-22																											
4	**Project Presentation**	**12-Jan-22**	**17-Jan-22**																											
4.01	Search for the media to use in the presentation	12-Jan-22	13-Jan-22																											
4.02	Script writing for the product pitch	13-Jan-22	15-Jan-22																											
4.03	Creating necessary animations	15-Jan-22	15-Jan-22																											
4.04	Placement of the vital data in the presentation	15-Jan-22	16-Jan-22																											

Taks ID	01-Nov-21	02-Nov-21	03-Nov-21	04-Nov-21	05-Nov-21	06-Nov-21	07-Nov-21	08-Nov-21	09-Nov-21	10-Nov-21	11-Nov-21	12-Nov-21	13-Nov-21	14-Nov-21	15-Nov-21	16-Nov-21	17-Nov-21	18-Nov-21	19-Nov-21	20-Nov-21	21-Nov-21	22-Nov-21
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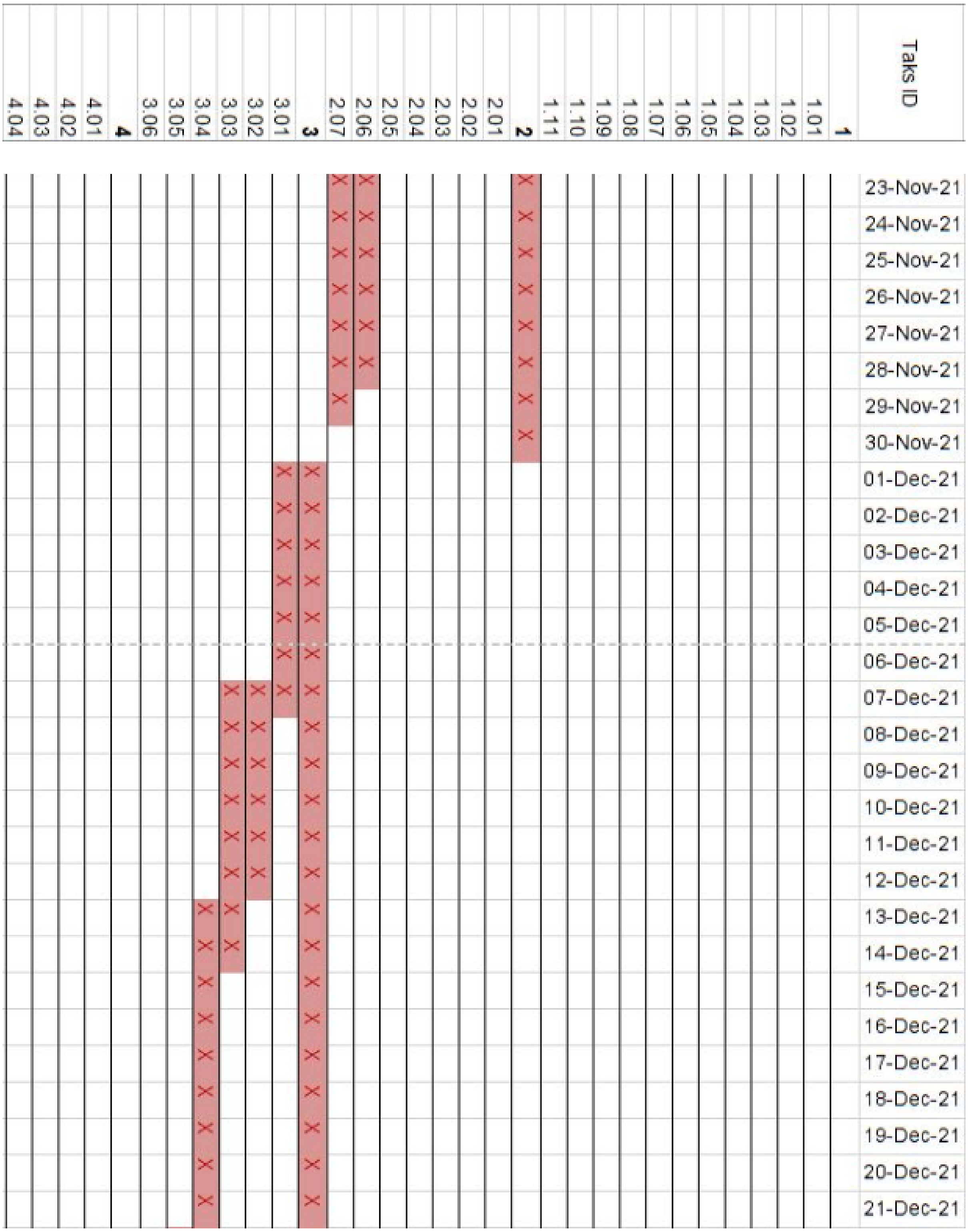
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Taks ID	22-Dec-21	23-Dec-21	24-Dec-21	25-Dec-21	26-Dec-21	27-Dec-21	28-Dec-21	29-Dec-21	30-Dec-21	31-Dec-21	01-Jan-22	02-Jan-22	03-Jan-22	04-Jan-22	05-Jan-22	06-Jan-22	07-Jan-22	08-Jan-22	09-Jan-22	10-Jan-22	11-Jan-22	12-Jan-22	13-Jan-22	14-Jan-22	15-Jan-22	16-Jan-22	17-Jan-22
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Work Packages

The number of work packages in such a complex project is high. From market research to the eventual product documentation a lot of steps have to be accomplished. Work packages are derived in such a manner that all the deliverables can be satisfied. Each package is assigned as a responsibility to a particular team member on the basis of their study course and talents. The following table shows work packages from each milestone and to whom it is allocated.

	Concept Design	**Product Design**	**Project Documentation**	**Product Presentation**
Syed-Talha Ahmed	Development of GANTT-chart Performing D-FMEA	Circuit Diagram Creation	Preparing the Bill of Materials (Electrical)	Search for the media used in the presentation
Pratyush Sharma	Allocation of Responsibilities Preparation of Functional Structure	Listing down the Requirements for buy parts	Drafting the Technical Drawings	Script writing for the product pitch
Syed-Moiz-Ud-Din Syed-Moin-Uddin	Fabrication of Work Packages Preparation of an initial sketch of SNARC	Designing the 3D CAD Model	Preparing the Bill of Materials (Mechanical)	Placement of the vital data in the Presentation.
Farah Kamal	Write the product description and executive summary List of Main Components	Creation of Activity Diagram Creation of State Machine Diagram	Writing the Pseudo Code	Creating the necessary animations.

Mahmoud-Mohamed-Osama-Mohamed Abdelhamid-Attia	Evaluation of the Market Size Price Prediction Planning of the Sales Volume	Taking ‘Make’ or ‘Buy’ Decisions Technology selection for make parts	Production Planning Cost Calculations	Search for the media used in the presentation

Functional Principles

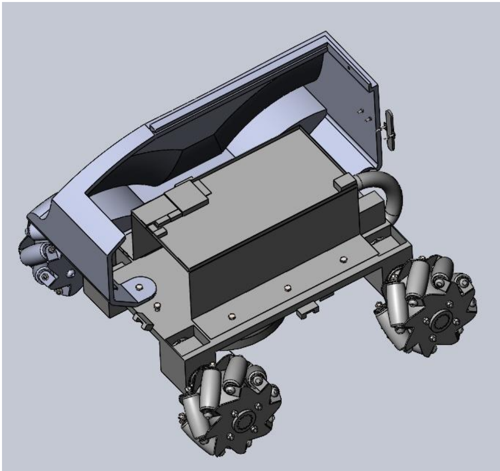


Figure 7. View of the inner components with the side hub wall removed

This section of the document exhibits the functions, activities, and the structuring of certain parts in the device. This section is supposed to help the reader understand the assembly of the parts in the device in a much easier way before the reader heads to view the CAD File.

Cutting Mechanism

The cutting mechanism consists of nylon blades, a small blade cover, and the DC motor that runs the blades. The mechanism works in a way that the DC motor uses electric power to rotate the nylon blades at a very high speed so that it can cut the crass very smoothly. In the Figure Below you can see the placement of the blades cover a little bit above the level of blades, it is done so that the cover does not touch the ground and does not damage itself and the cobblestones. The blade cover is attached to the chassis through bolting. The depth of the blades reaches almost the bottom level of the mecanum wheels. This is done so that the grass can be cut as finely as possible.

Vacuum Cleaning Mechanism

SNARC uses a vacuum to clean up the grass that was cut. This also cleans up the dirt from the cobblestones. This mechanism consists of a DC motor and a controller that activates the vacuum and then the attached tube siphons up the small debris nearby. The pipe is attached to a funnel on one end, so that it can cover more area. All this debris is then collected in a bag, and the machine indicates when the bag needs to be emptied.

Chassis

The chassis holds the weight of everything on itself. It is the core of the entire structure. It holds the place for all the mechanical and electronic components on itself. The housing for the device is placed on top of it and is fixed by screwing. It grips all the components so that the components do not move while the device is performing its primary and secondary functions.

Activity Diagram

The main function in SNARC is navigation. When the battery is low, vacuum is full, motor is overheating, memory is full, or there is an obstacle or border present, an interrupt signal is sent to execute the respective command.

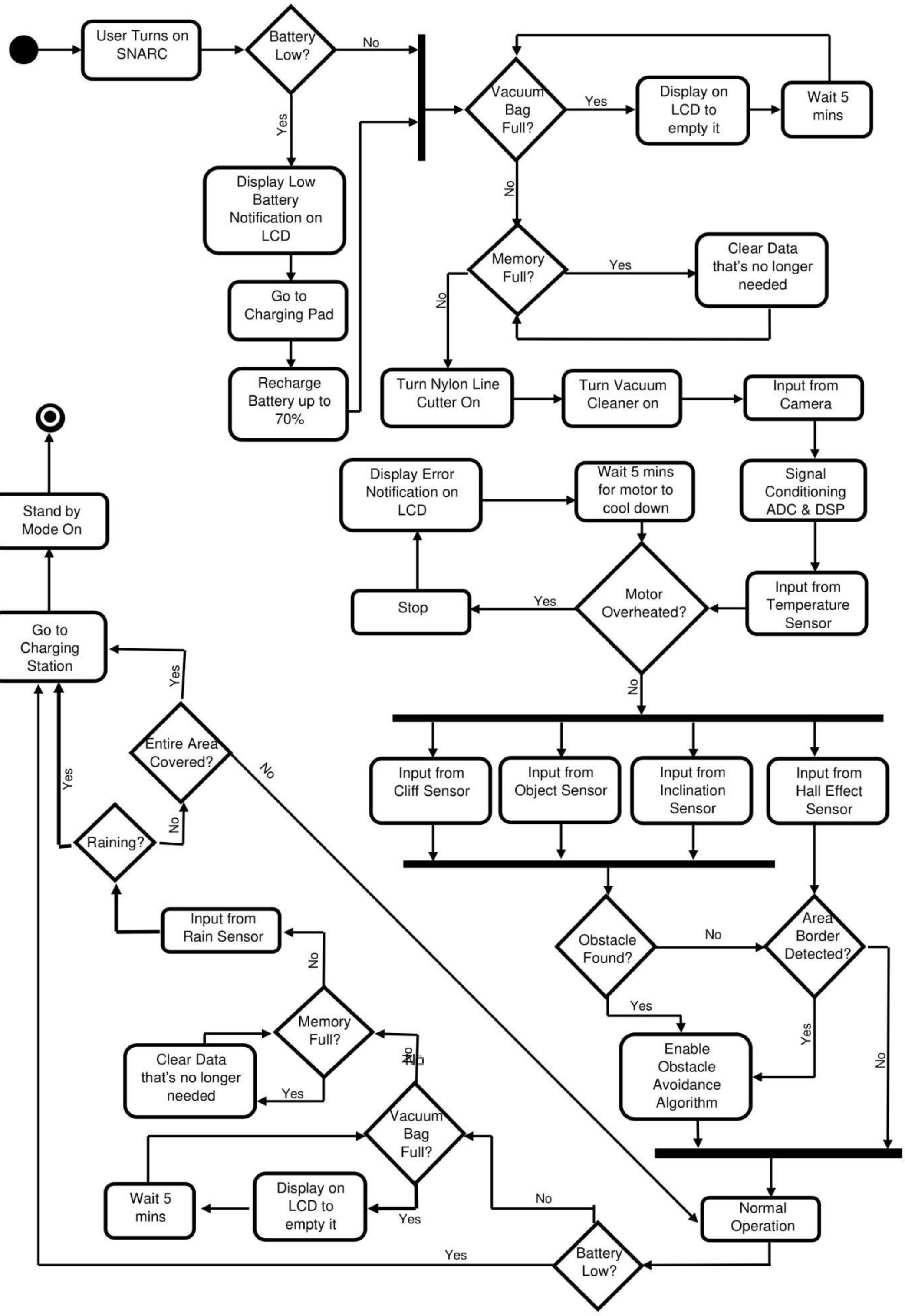


Figure 8. Activity Diagram

Circuit design

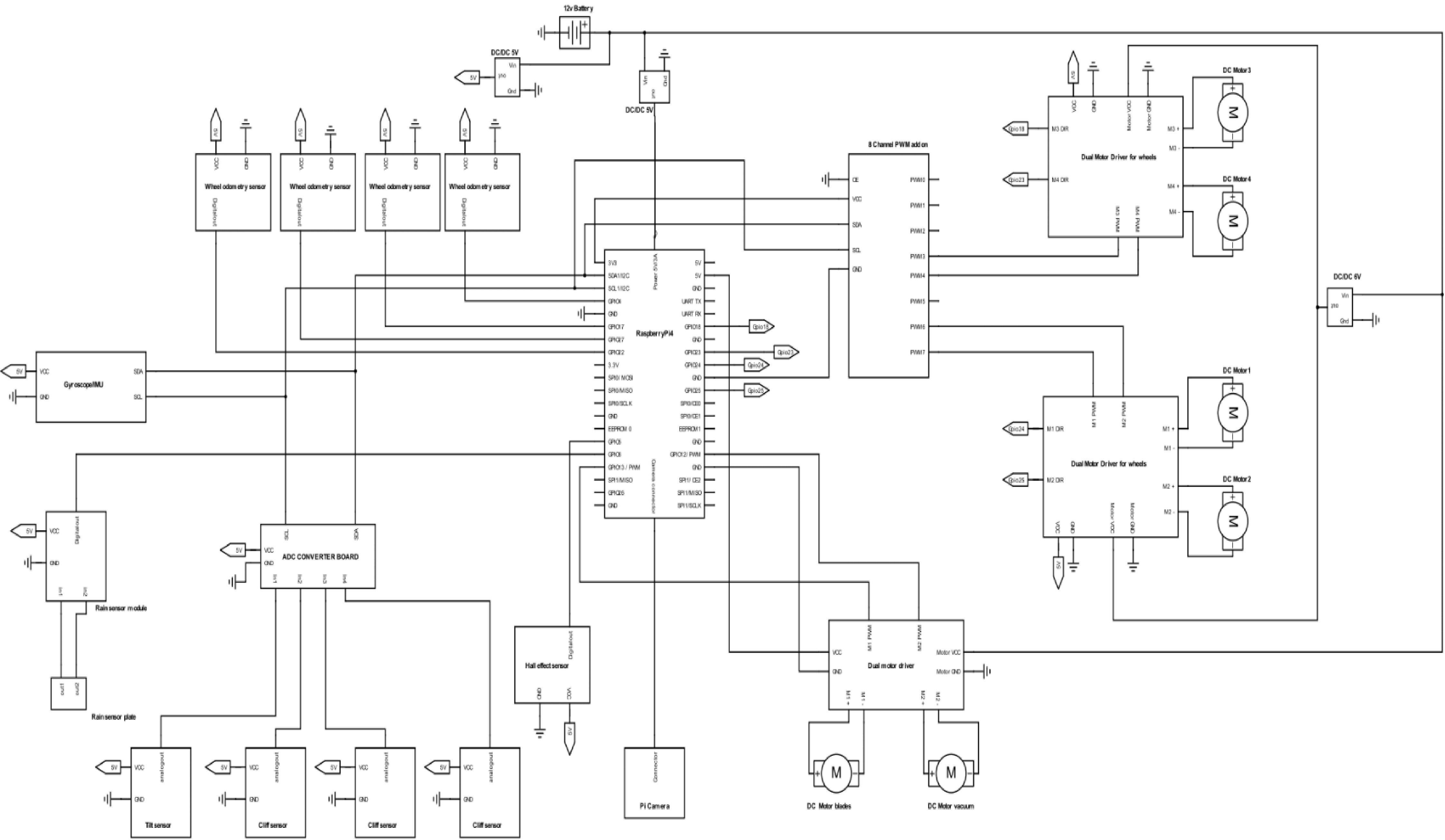
The symbols used in the schematic are modeled after the linked add-on modules and are simplified versions, but any similar module would have the same input and output pins. The boards

The motors are the only components powered directly by the 12V DC battery. Appropriate DC/DC step down converters are used to power the rest of the components, including the Raspberry Pi itself.

The dual motor driver for vacuum and blade motors is controlled with the PWM pins of the Pi and powered by the 5V supply on the Pi. It contains overheat protection and reverse current protection already.

The 8 channel PWM add-on module is used to provide additional PWM channels to control the speed of the DC motors. The direction control of the motors is connected directly with the GPIO pins. The dual motor driver for wheels is powered by the 5V connection but the power for the motor comes from the 6V step down dc/dc converter, since the dc motor for wheels need 6V to operate.
The I2C bus is used to communicate with slave devices such as the ADC converter board, the PWM add on and the gyroscope sensor. The Pi can receive information from many different sensors through simply the two SDC and SCL pins since all the slave devices have different addresses, including the sensors connected to the ADC board.

Sensors like Hall effect, wheel odometry and rain sensor have digital output possible so their outputs can be directly connected to any GPIO pin on the Pi.



12v Battery
DC/DC 5V
DC/DC 5V
DC/DC 6V
Wheel odometry sensor
Wheel odometry sensor
Wheel odometry sensor
Wheel odometry sensor
8 Channel PWM addon
Dual Motor Driver for wheels
Dual Motor Driver for wheels
DC Motor3
DC Motor4
DC Motor1
DC Motor2
RaspberryPi4
Gyroscope/IMU
ADC CONVERTER BOARD
Rain sensor module
Rain sensor plate
Hall effect sensor
Pi Camera
Dual motor driver
DC Motor blades
DC Motor vacuum
Tilt sensor
Cliff sensor
Cliff sensor
Cliff sensor

Battery voltage monitor circuit

A Battery's voltage drops when it discharges so to measure the health of the battery and the charge left, a voltage sensor module is used. It consists of a standard voltage divider circuit. Connecting it across the battery terminals measures the output and connects the analog output through the ADC to the Pi, if and else statements could then be used to command the robot to approach the charging station once the battery has discharged a specified amount.

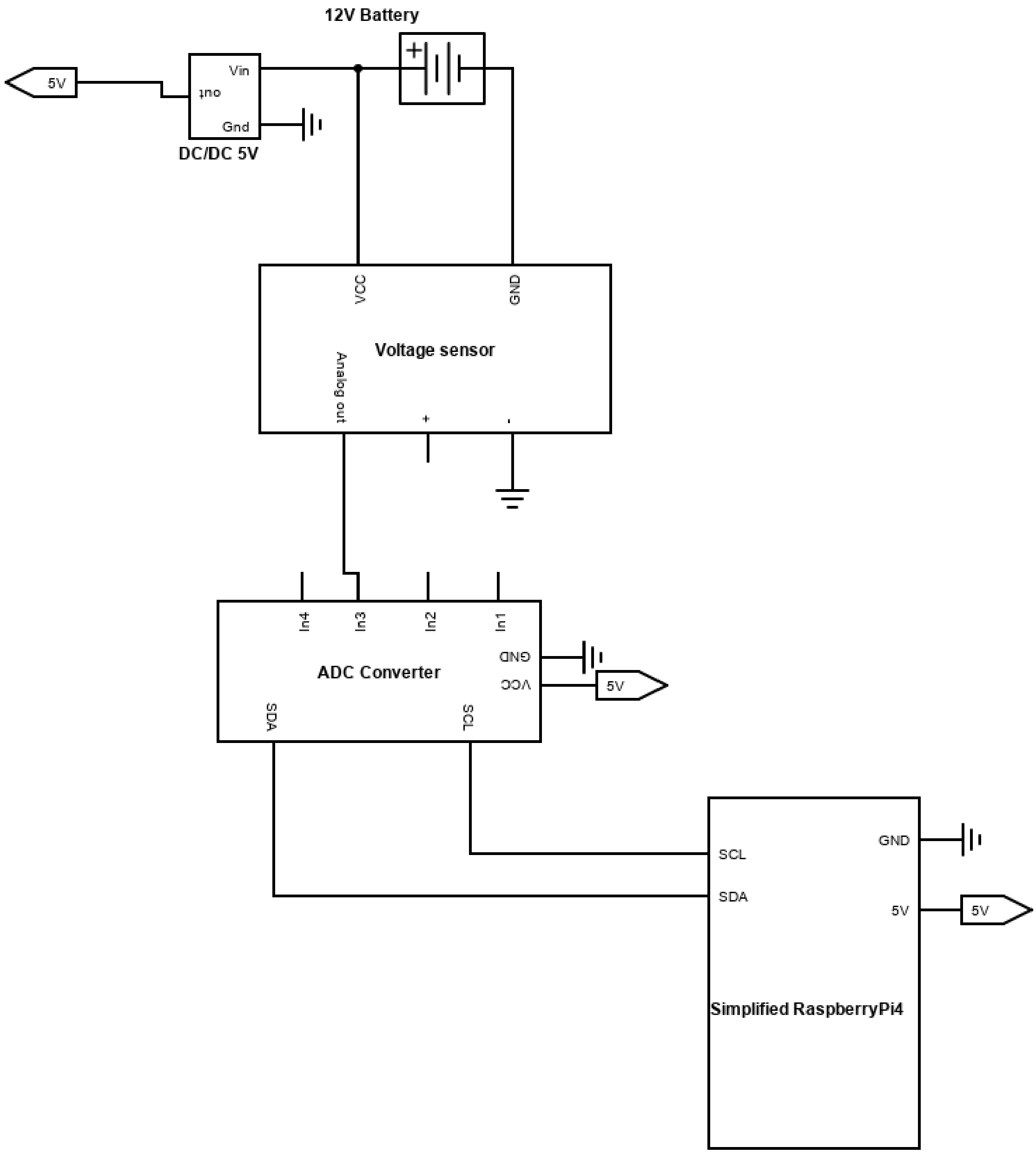


Figure 9. Battery voltage monitor circuit

PCB Board dimensions

The PCB board dimensions will be approximated according to the modules referenced. The other dimensions are standard dimensions for a module like that. According to the CAD design, the empty space on the plate for boards is around *450 x 220 mm.* This is plenty of space for all the boards to fit in the space and have leftover space for wires.

The dimensions of the relevant boards are mentioned below :

-Raspberry Pi : 85mm x 56mm [40]

-3x DC dual motor driver : 73mm x 68mm [32]

-PWM add on module : 50mm x 25mm

-ADC converter board : 10mm x 5mm

Sensor boards on the main plate alongside the above boards :

- Tilt sensor : 30mm x15mm [33]

- Rain sensor : 32mm x 14mm [37]

- Gyroscope sensor : 30mm x 20mm

- Voltage sensor 40mm × 30mm

The diagram on the next page shows how the boards could be placed, the ratios are kept intact. The conclusion from the drawing is that there would be more than enough space for the connections between the modules without jamming the components all together.

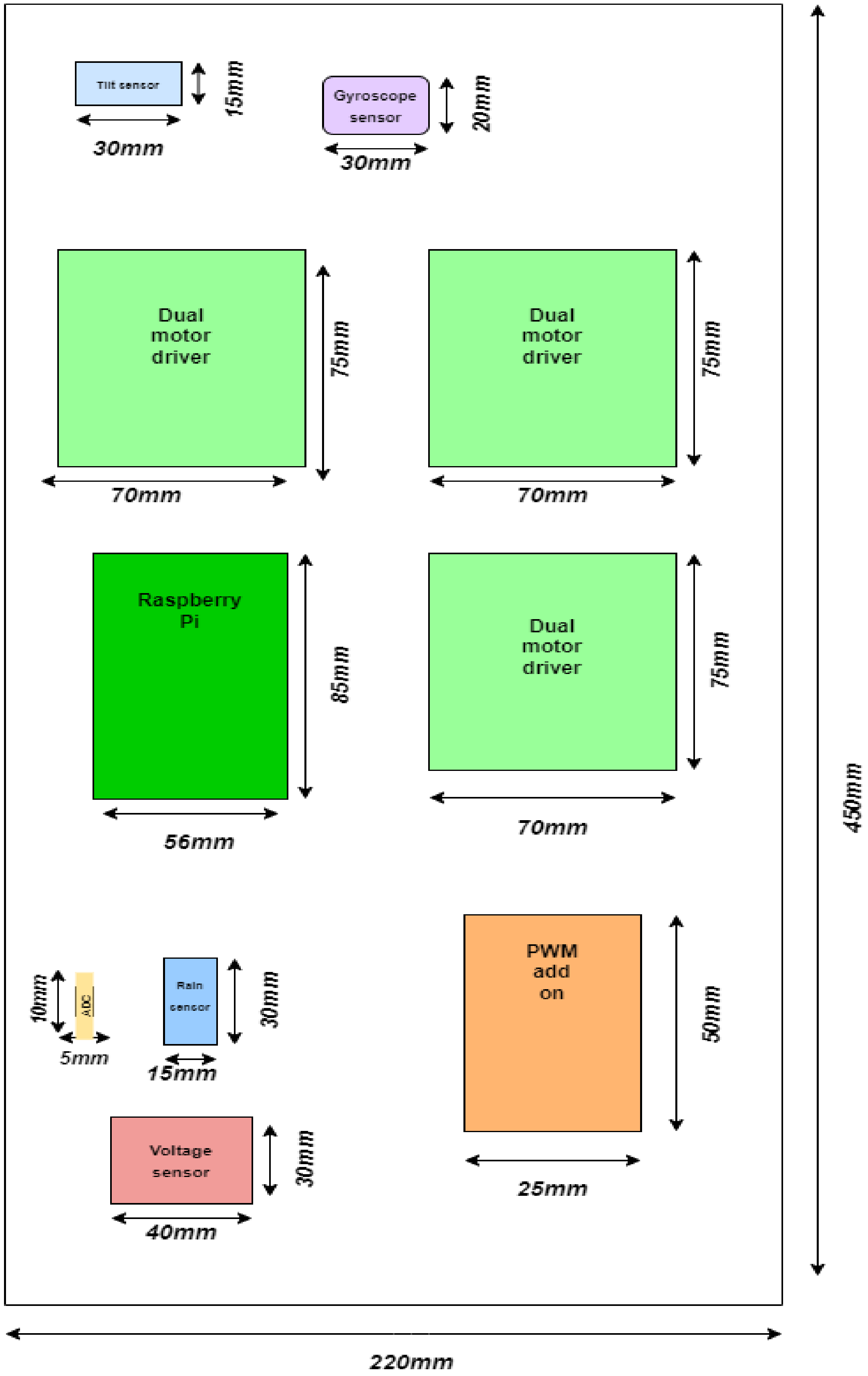


Figure 10. PCB circuit board

Make or buy Decisions

Introduction

Make or buy decision is one of the most significant decisions taken by the management of the company. It defines the cost structure and breakeven analysis of the firm and its products, the unique selling advantages, and the layout of the factory. Make or buy decisions depend on the production volume and the capability of covering the fixed costs used in the production process and also depend on the standardization of a part or a component.

An overwhelming pattern visible would be that most mechanical parts are made and most electrical parts are bought. This is not a coincidence but rather a decision to maximize economical advantage and design efficiency. Ready made electronic components are better utilized because they are standardized and easier to connect. Mechanical design however is usually customized for different applications. The below criteria sums up the decision rationale for the list on the following page.

Criteria

Make Decision		**Buy Decision**	
The making cost is lower than the buying prices.	A	Selling revenue can not cover the making cost.	D
The desired Component not available in the market.	B	The desired component is available and standardized.	E
Customized by engineers.	C	Making the part or the component is very complex and requires non available technologies.	F

List of Components

Sub-Assembly	Part No.	Part Name	#	Material	Decision Selection	Reason
Mechanical	M_01	Hub wall	2	PVC-R	Make	C
	M_02	Chassis	1	3003 Aluminum Alloy	Make	C
	M_03	Hub Cover	1	PVC-R	Make	C
	M_04	Shafts	5	3003 Aluminum Alloy	Make	A
	M_05	Funnel (Vacuum Pipe)	1	Propylene	Make	B
	M_06	Vacuum Pipe	1	PVC-R	Make	A
	M_07	Vacuum Bag	1	Non Woven cloth	Make	A
	M_08	Vacuum Pipe Bracket	1	Stainless steel 1.4003 (X2CrNi12)	Make	A
	M_09	Cutter Cover	1	Stainless steel 1.4003 (X2CrNi12)	Make	C
	M_10	Nylon Wire Holder	1	Steel 1.5918 (17CrNi6-6)	Make	C
	M_11	Shelf	1	Aluminum Alloy 3003	Make	C
	M_12	Charger	1	Aluminum Alloy 3003	Make	C, B
	M_13	Bolt DIN EN 28765 – M8x1 x 45 x 22-N	10		Buy	E

Sub-Assembly	Part No.	Part Name	#	Material	Decision Selection	Reason
	M_14	Bolt DIN EN 24014 – M4 x 35 x14-N	10		Buy	E
	M_15	Hexagon Nut ISO 4036 – M8 - N	10		Buy	E
	M_16	Hexagon Nut ISO 4036 – M4 – N	10		Buy	E
	M_17	Bearing DIN 625 - 6008 - 16,SI,NC, 16_68	5		Buy	E
	M_18	Nylon Wire	0.5m		Buy	E
	M_19	Mecanum Wheels	4		Buy	E
Electrical	E_01	Battery	1		Buy	E, F
	E_02	Raspberry Pi	1		Buy	E
	E_03	ADC converter board	1		Buy	E
	E_04	Add-on board for PWM	1		Buy	E
	E_05	Dual Motor Driver	3		Buy	E
	E_06	DC Motor	6		Buy	E, D
	E_07	DC/DC Step down converters	3		Buy	E
	E_08	Pi Camera	1		Buy	E, F
	E_9	Cliff sensor	3		Buy	E
	E_10	Object sensor	1		Buy	E
	E_11	Hall effect sensor	1		Buy	E

Sub-Assembly	Part No.	Part Name	#	Material	Decision Selection	Reason
	E_12	Wheel Odometry sensor	4		Buy	E
	E_13	Rain sensor	1		Buy	E
	E_14	Incline sensor	1		Buy	E
	E_16	LCD screen	1		Buy	E, F
	E_17	Gyroscope/IMU	1		Buy	E
	E-18	Pushbutton	2		Buy	E
	E-19	Voltage sensor	1		Buy	E
	E-20	IR emitter	1		Buy	E
	E-21	IR receiver	1		Buy	E
	E-22	Small microcontroller	1		Buy	E, F

Technology Selection for the “Make” Parts

This section shows technologies that will be used in the production of parts that are being manufactured in house by the company. Various technologies are used based on the shape, size, and function of the part. The reason behind the technology selection has been given for each part.

Housing Wall

Quantity:	2
Material:	PVC-R
Technology Selection:	Injection Molding
Explanation:	This part has been designed in such a way that the manufacturing of the part does not become a major issue. The walls for the hub of the device are designed as two separate parts (left and right side). Both the parts have their separate dyes. The part has a draft angle so that the ejection of the part from the mold gets easier.
Part Description:	It is made to cover up all the electronics inside it and prevent the dust and other stuff that might have the potential to damage the circuits, microcontroller, or the motor.

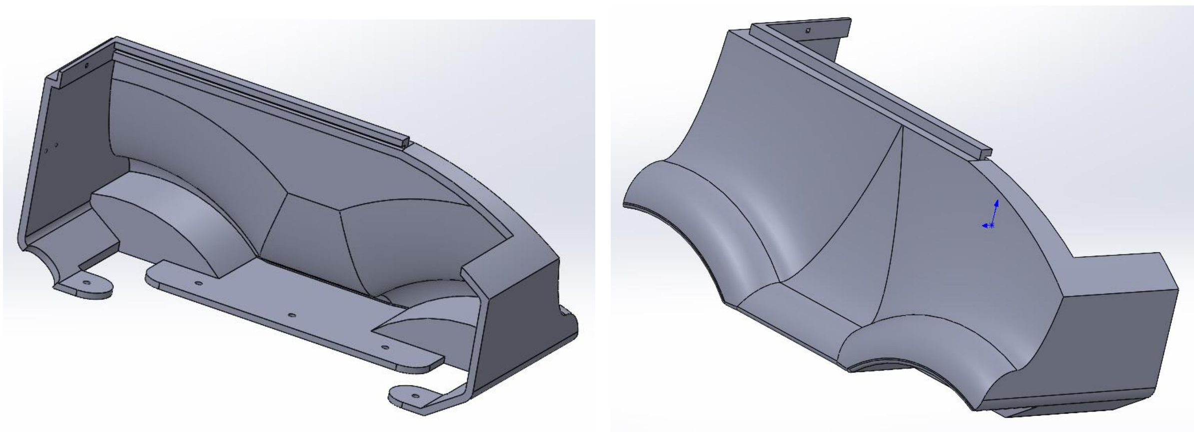


Figure 11. Hub Walls (Both right and left)

Chassis

Quantity:	1
Material:	3003 Aluminum Alloy
Technology Selection:	CNC(Milling)
Explanation:	The CNC milling is used to extract the major outer shape of the chassis from the alloy provided by the supplier. Once the shape of the chassis is obtained by the milling machine, it drills the required holes for bolts and the cutting mechanism.
Part Description:	The chassis holds the weight of everything on itself. It is the core of the entire structure. It holds the place for all the mechanical and electronic components on itself. The housing for the device is placed on top of it and is fixed by screwing. It grips all the components so that the components do not move while the device is performing its primary and secondary functions.

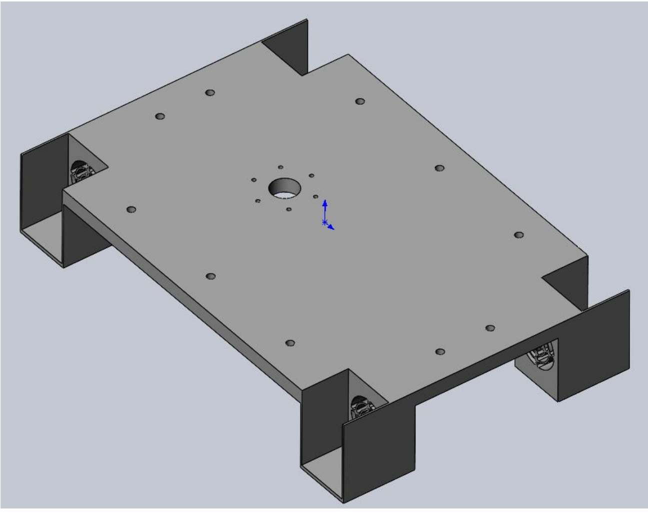


Figure 12: Chassis

Hub Cover

Quantity:	1
Material:	PVC-R
Technology Selection:	Injection Molding
Explanation:	The CNC milling is used to extract the major outer shape of the chassis from the alloy provided by the supplier. Once the shape of the chassis is obtained by the milling machine, it drills the required holes for bolts and

	the cutting mechanism.
Part Description:	This is the lid on top of the housing walls. It covers the device housing from the top. It is not bolted to the walls but rather just connected with a hinge. So, it remains easy to remove. Hence, servicing of the parts or changing the vacuum bag is not a very hard task.

Shafts

Quantity:	4(from dc motors to mecanum wheels) + 1(from DC motor to the Nylon Cutting Blades)
Material:	6061 Aluminum
Technology Selection:	Lathing(turning), Grinding
Explanation:	The lower pole has a hollow cylindrical shape. To obtain that shape the rod has to undergo the process of turning on a lathe. Then to remove the feed marks from the surface and to obtain a better surface finish the part undergoes grinding. After the outside shape is formed then the inner side of the pole is done by drilling. Surface roughness is not a concern here.
Part Description:	The shafts are being used to supply the power from the motor to the other end (in once case the wheels, in other case it's the nylon blades). It also transfers the force from one end to end and helps the wheels and blades stay in the same position relative to the chassis while rotating around the respective shafts.

Funnel(Vacuum Pipe)

Quantity:	1
Material:	Propylene
Technology Selection:	Injection Molding
Explanation:	The geometry of the part is difficult to produce with other methods of production. The material choice is also responsible for this method of production. The funnel is created separated in two parts(upper and lower), but contrary to the Hub Walls, here both sub-parts share the same dye. After the parts have been molded, they are joined by Overmolding.

Part Description:	It expands the area covered by the device to clean the cobblestones by vacuum suction method.

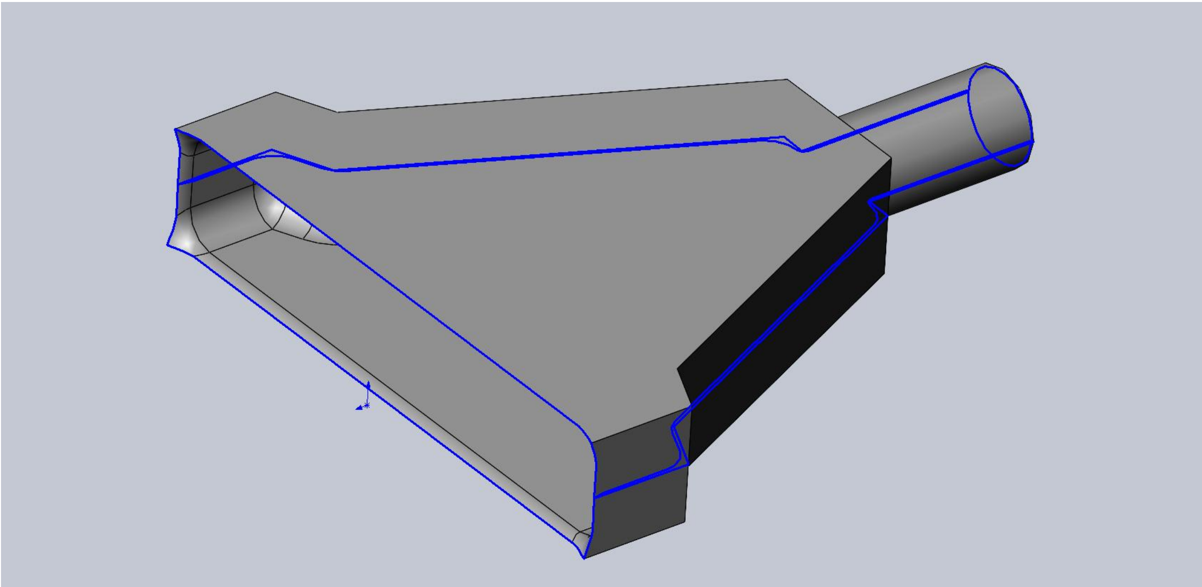


Figure 13. The Blue line Indicates The Parting Line

Vacuum Pipe

Quantity:	1
Material:	PVC-R
Technology Selection:	Extrusion, Heat Induction Bending
Explanation:	Extrusion was the easiest way to process PVC into a hollow cylindrical pipe. Since PVC is a thermoplastic, it can be bent after by heating, with a process called Heat Induction Bending.
Part Description:	This pipe is used as a way of movement in between the vacuum funnel and the vacuum bag. It transports debris to the vacuum bag.

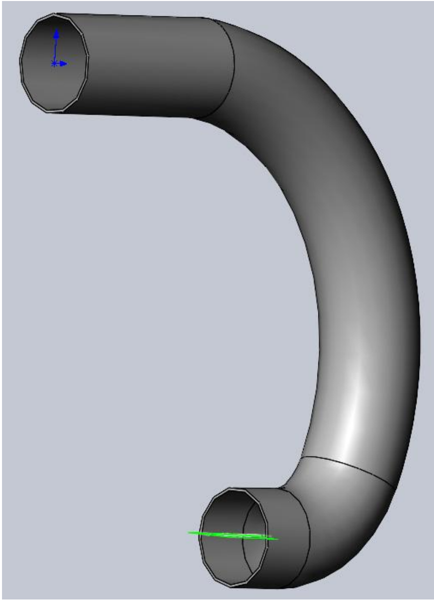


Figure 14. Vacuum pipe

Vacuum Bag

Quantity:	1
Material:	Non Woven cloth
Technology Selection:	Cutting, and stitching
Explanation:	The part is created with non woven cloth. Piece of cloth is cut according to the required dimensions and then it is stitched in a way that it makes the part that is shown in the figure. The choice of material makes it washable, so that it can be reused multiple times. Hence, making it a much safer choice for the environment.
Part Description:	The part is used for storing all the leaves or other debris lifted up by the suction of the vacuum.

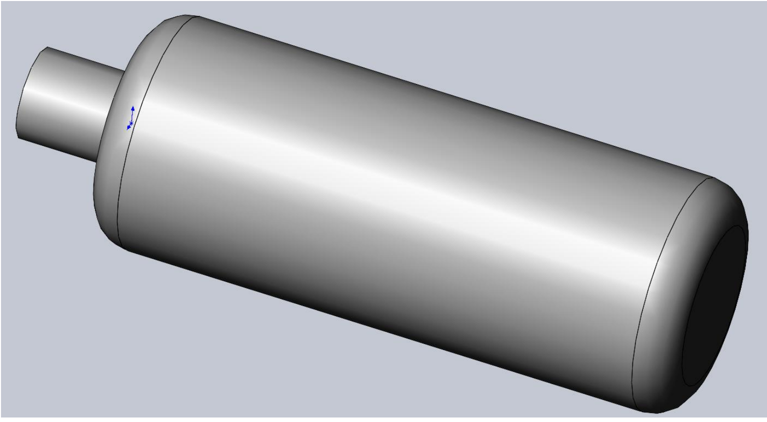


Figure 15. Vacuum bag

Vacuum Pipe Bracket

Quantity:	1
Material:	Stainless steel 1.4003 (X2CrNi12)
Technology Selection:	CNC (milling)
Explanation:	The bracket is made by machining out from the raw stainless steel provided by the supplier. The raw material is first milled in the CNC so that it can acquire the required shape. After it acquires the desired shape then it undergoes drilling where the hole for the vacuum pipe is made. And then the part is rotated 90° and then the holes for the bolts are made.
Part Description:	The part is used to hold the vacuum pipe so that it doesn't move or vibrates a lot. It keeps the pipe at its place and provides the support to the pipe so that it doesn't just hang from the Hub Walls.

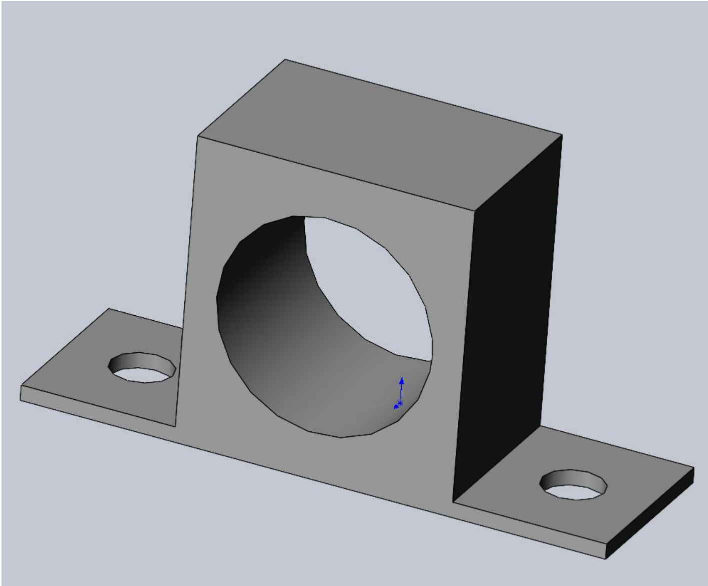


Figure 16. Vacuum pipe bracket

Cutter Cover

Quantity:	1
Material:	Stainless steel 1.4003 (X2CrNi12)
Technology Selection:	Lathe (Turning), Drilling
Explanation:	The part is machined to its final state from the raw material provided by the supplier. The part is first machined in the lathe machine, it undergoes the process of turning there and gets its outer shape. Then it undergoes drilling so that the holes for the main shaft and the bolts can be made there.
Part Description:	It is placed on top of the nylon cutting blades so that the weed that has just been cut doesn't come flying to the chassis right away.

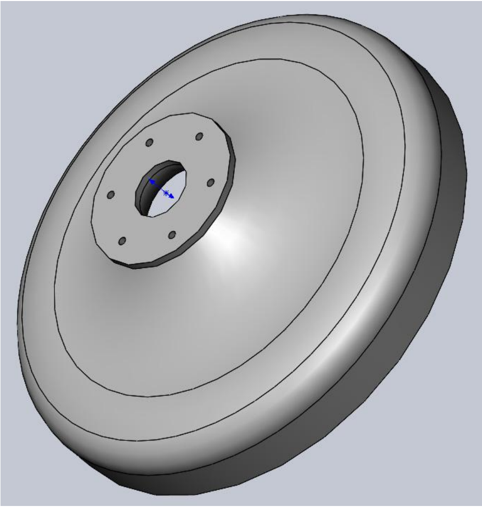


Figure 17. Cutter cover

Nylon Wire Holder

Quantity:	1
Material:	Steel 1.5918 (17CrNi6-6)
Technology Selection:	Lathe (Turning), Drilling
Explanation:	The part is machined to its final state from the raw material provided by the supplier. The part is first machined in the lathe machine, it undergoes the process of turning there and gets its outer shape. Then it undergoes drilling so that the holes for the main shaft and the thread can be made there.
Part Description:	The Nylon wire that is used for cutting the weed is wrapped around for this part. It lets some of it hang out, that is the part that cuts the weed the rest of the nylon wire is wound up tightly around the holder, this adds to extra grip for the wire.

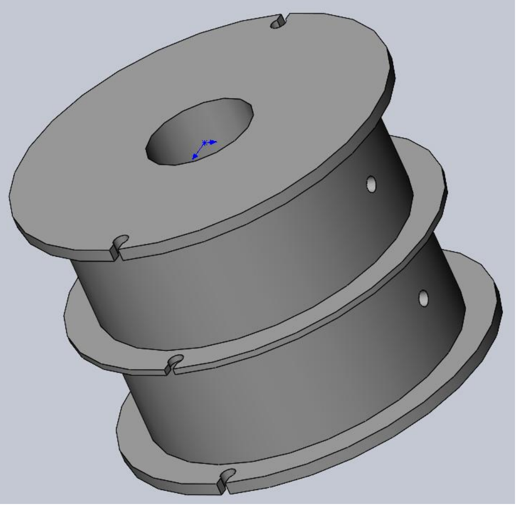


Figure 18. Nylon wire holder

Shelf

Quantity:	1
Material:	Aluminum Alloy 3003
Technology Selection:	Sheet Metal Folding, Drilling
Explanation:	For this part the material comes as a raw sheet and then it gets cut into required size and then it undergoes the process of sheet metal bending in a press and thus it acquires the desired shape. The remaining work is to add holes in this for the bolts so that it can remain in place.
Part Description:	This part is used as a surface to keep the circuit boards in place. Since the chassis is filled with the other motors and the compartments of the vacuum. This works as a good way to utilize space in a more sustainable manner.

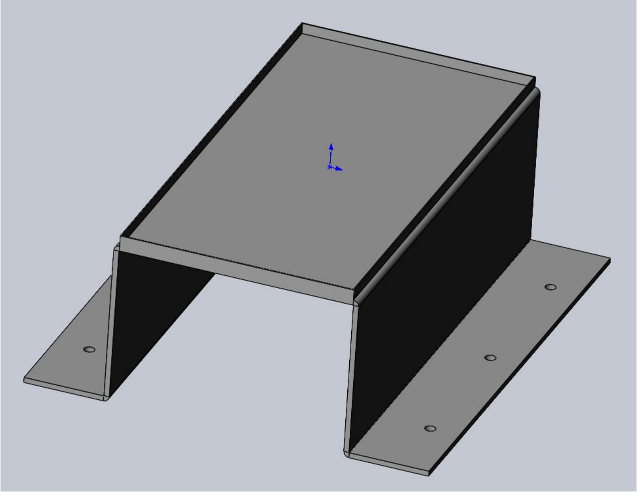


Figure 19. Aluminum alloy shelf

Charger

Quantity:	1
Material:	Stainless steel 1.4003 (X2CrNi12)
Technology Selection:	CNC (Milling), Grinding
Explanation:	The part first goes under a CNC machine and then it gets the desired shape and all the holes for electrodes needed. Then the part is grinded to provide the required amount of finish at the surface.
Part Description:	This is the part that is connected to a source of electricity and works as a transporter of charge from the source to the battery present in the device. This is also the place where the device heads to when it is put in standby mode or when it is not in use.

Requirements manual

For the prototype of the robot, the requirements manual is laid out on the next few pages . The following paragraphs serve to justify some of the decisions for the requirements and ultimately classifying all electronic components as buy decisions. It is to be noted that most modules linked and requirements specified are from ready-made branded products. However, in a mass production scenario, to cut future costs far cheaper alternatives and customizable options will be preferable as is the case for the Raspberry Pi for example.

Starting with the battery, $12V$ is chosen because it's the highest operating voltage a component requires in the robot. A capacity of $15000mAh$ is chosen because the total current requirement comes out to be around $30A$. Assuming operation time to be around 30 minutes, according to the formula :

$$Time\ in\ h = Battery\ supply\ in\ mAh\ /\ current\ consumption\ in\ mA$$
$$0.5h = x/30000\ mA$$
$$x = 15000mAh$$

The C rating is calculated according to the formula :

$$C * Capacity\ in\ mAh = max\ current\ in\ mA$$
$$C = 30000mA/15000mAh$$
$$C = 2$$

A voltage sensor, consisting of a voltage divider circuit is used to monitor battery voltage and send a signal to the Pi when the battery discharges, so the robot can start finding it's charging dock.
The Raspberry Pi 4 is the choice for the main processor board because of its unrivaled image processing capabilities complimented nicely with its own revered Pi camera, alongside a plethora of GPIO pins to use. However, the Pi only uses digital inputs so an ADC converter is additionally required for sensor outputs to be processed.

Another important aspect of the Pi is the provision of the I2C bus which can connect many different devices as 'slaves' as long as they have a different address each. Usually, the SDA and SCL lines are pulled up to VCC with a resistor, however all the devices that use I2C communication are mounted on their own little PCB, both lines already using a pull up resistor. This is the case with the ADC converter, PWM add-on module and gyroscope sensor and is a main advantage of buying instead of making these parts.

Furthermore, coupled with the fact that they have their own board, the connections are simplified and costs are reduced because a PCB does not have to be manufactured and no additional components need to be soldered.

This is also precisely the reason a dual motor driver board that has reverse current protection, and overheating protection, amongst other things, is chosen. The schematic is much simpler and direct from board to board. Having the liberty to buy ready-made boards allows for a greater number of features in a board. Moreover, it was essential that the dual motor board's voltage and continuous current has to match the motor and it's peak current output should be more than the peak current required by the motors otherwise there is a risk of burnout.

The DC motor for blades is chosen for it's relatively high current rating because current is proportional to the torque and the cutting mechanism needs a high torque to be able to cut overgrown plants. The gearbox is desired as well since torque multiplication can be achieved with gearing.
As for the DC motor for the vacuum, specifications for components such as the motor do not necessarily relate to the performance of the entire vacuum cleaner [29] The motor would be connected to a blower module responsible for the suction. Lower noise is a desired outcome so therefore a brushless DC motor is preferred. The current rating is lesser but a suction motor needs a high rpm because the blower spins faster therefore making it powerful enough to suck in excess plants.

Dual motor controllers are required for the wheel motors. There is a separate supply port on the controllers for the motors. To add to that, reverse current protection is necessary because Mecanum wheel vibrations can create noise and affect stability of motor currents. The weight of the robot is assumed to be around 15kg, dividing that by 4 wheels, that gets 3.75kg/wheel. The static coefficient of friction μ_s of soft rubber on concrete is 0.85 [45]. The robot has to overcome static friction F_{MAX} to be able to move :

$$F_{MAX} = mg * \mu_s$$

$$F_{MAX} = 3.75*9.81*0.85$$

$$= 31.3\text{N}$$

Multiplying the static friction force F_{MAX} with the radius r of Mecanum wheel which is around 10cm , it gives the torque τ needed to move one wheel of the robot.

$$\tau = F_{MAX} * r$$

$$\tau = 31.3 * 0.1$$

$$\tau = 3.13\ \text{Nm}$$

Knowing the torque requirements and the torque a DC motor can provide, gearbox ratios can be calculated. If a motor can output 0.3Nm of torque, an amplifying gearbox ratio of 1:10 can be used to achieve the required torque to move the wheels.

Finally, an array of sensors are used, but all mounted on a board with appropriate pin outs to be able to be connected to the Pi, either through I2C, or directly to a GPIO pin.
To ease the software and code required for localization, sensors such as wheel odometry, hall effect and gyroscope are used in combination with the vision system to allow SNARC to navigate along the intended path.

As for the charging dock, apart from the contact electrodes, the electronic components needed are a IR emitter connected with an Arduino or similar small microcontroller programmed to be able to flash it at a high frequency.
A corresponding high pass IR receiver on the robot allows it to detect the frequency and allows it to find the charging dock. This is an additional help in the docking process since localization techniques are already implemented with other sensors and the vision system.

Electronics Parts

Component	Specifications	Number of pieces	Supply Voltage (V)	Supply Current (mA) unless specified
Battery	-Capacity : 15000 mAh -C- rating : 2C -Runtime : min 30 minutes -Rechargeable	1	12	-
Microprocessor	-Raspberry Pi 4 -40 GPIO Pins -I2C communication and camera port	1	5	3A
ADC converter board	-Uses I2C communication -Min 4 analog inputs -Gain amplifier	1	2-5	Standard <1
Add-on board for PWM	-Min 4 PWM output connections (standard 8)	1	Standard 3.3	20-30

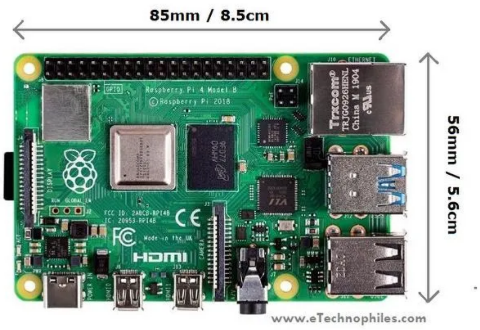


Figure 20: Raspberry Pi 4 [40]

Component	Specifications	Number of pieces	Supply Voltage (V)	Supply Current (mA) unless specified
Dual Motor Driver	- Continuous output current min 10A for both motors - Peak output current min 20A for both motors - Min 2 PWM output pins to Pi to control motor - Galvanic isolation to protect Pi - Integrated temperature sensor for overheat protection - Short circuit protection - Overvoltage lock - Current limitation mechanism	1	5	<30

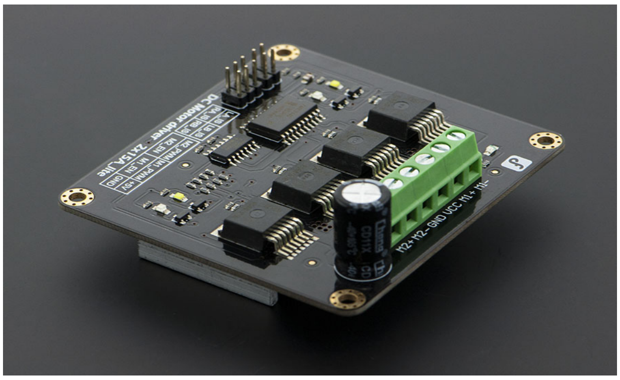


Figure 21: Possible module Dual motor driver [32]

DC Motor for blades	- Continuous output current 10A - Peak output current max 20A - Gearbox included - High torque min 1Nm - 2000-4000 rpm	1	12	10A
DC Motor for vacuum	-Continuous output current max 10A, usually below 5A - Peak output current max 20A - Brushless, low noise - High speed, 6000 - 10000rpm	1	12	<= 5A

Component	Specifications	Number of pieces	Supply Voltage (V)	Supply Current (mA) unless specified
DC motors for mecanum wheels	- Encoders and gearbox included - High torque up to 0.5Nm - Peak current below 5A -Continuous current 3A	4	6	<5A
Dual Motor driver for motors for wheels	- under-voltage, over-current, and over-temperature protection - reverse current protection - Speed and direction control both included - Reverse current protection - Peak output current min 5A - Continuous current ~3A each motor channel	2	3-5	<30
DC/DC Step down converters	- UBEC or similar - 2x 5V DC/DC step down - 1x 6V DC/DC Step down - must have appropriate heatsink	3	6-16	1-2A
Pi Camera	Connects to Pi with a special ribbon cable included	1		250
Object sensor	-contact object sensing -Digital output	1	3.3 - 5	30

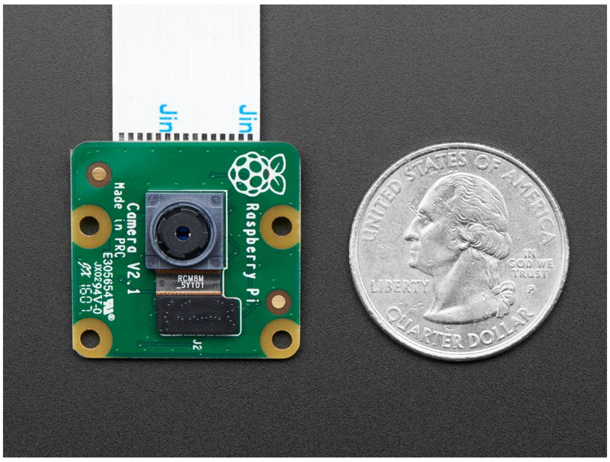


Figure 22. Pi Camera next to a quarter [42]

Component	**Specifications**	**Number of pieces**	**Supply Voltage (V)**	**Supply Current (mA) unless specified**
Hall effect sensor	- High stability with regards to temperature change - Reverse supply protection - Digital output - Uses DRV5053 sensor -Uses LM393 as comparator	1	3.3-5	~ 2-5
Wheel Odometry sensor	- IR speed sensors used for localization - Encoder discs included - Digital output - Uses LM393 as comparator	4	3.3 - 5	< 50
Voltage sensor	- Accepts more than 12V - analog output	1	5-15	
Rain sensor	- comes with sensing pad with two header pins, size < 3x3 cm - sensor pcb module should have digital output	1	3.3- 5	15
Incline sensor	-Tilt sensor with metallic ball mechanism - Analog output - Uses LM393 as comparator	1	3.3-5	200
Gyroscope/IMU	3-axis gyroscope 3- axis accelerometer Uses I2C communication Wide temperature range of -40°C - +85°C Clock frequency of max 400kHz	1	2.4 - 3.6	< 20
Mecanum Wheels	- Can support upto 15kg - 2x right sided, 2x left sided	4		

Component	**Specifications**	**Number of pieces**	**Supply Voltage (V)**	**Supply Current (mA) unless specified**
Cliff sensor	-IR distance sensors -Analog output	3	3.3 - 5	50

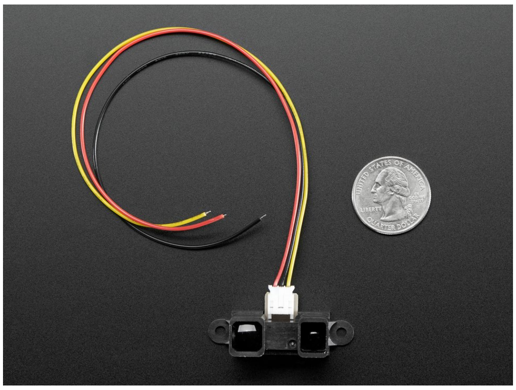


Figure 23. Cliff sensor next to a quarter [40]

IR emitter	- Can emit high frequencies - Used for charging dock	1		
IR receiver	- with high pass filter - Used for finding charging dock	1		
Microcontroller	- basic microcontroller - able to be programmed in standard languages	1	-	-

Mechanical Parts

Bolts

Standard	Quantity
DIN EN 28765 - M8 x 1 x 45 x 22-N	10
DIN EN 27014 - M4 x 35 x 14-N	10

Table 18.

Figure 24. Bolt

Nut

Standard	Quantity
Hexagon Nut ISO 4036 - M8 - N	10
Hexagon Nut ISO 4036 - M4 - N	10

Table 19.

Figure 25. Nut

Bearings

Standard	Quantity
SKF 7003 CD/HCP4AH	1
DIN 625 - 6008 - 16,SI,NC, 16_68	4

Table 20.

Figure 26. Ball-Bearing[]

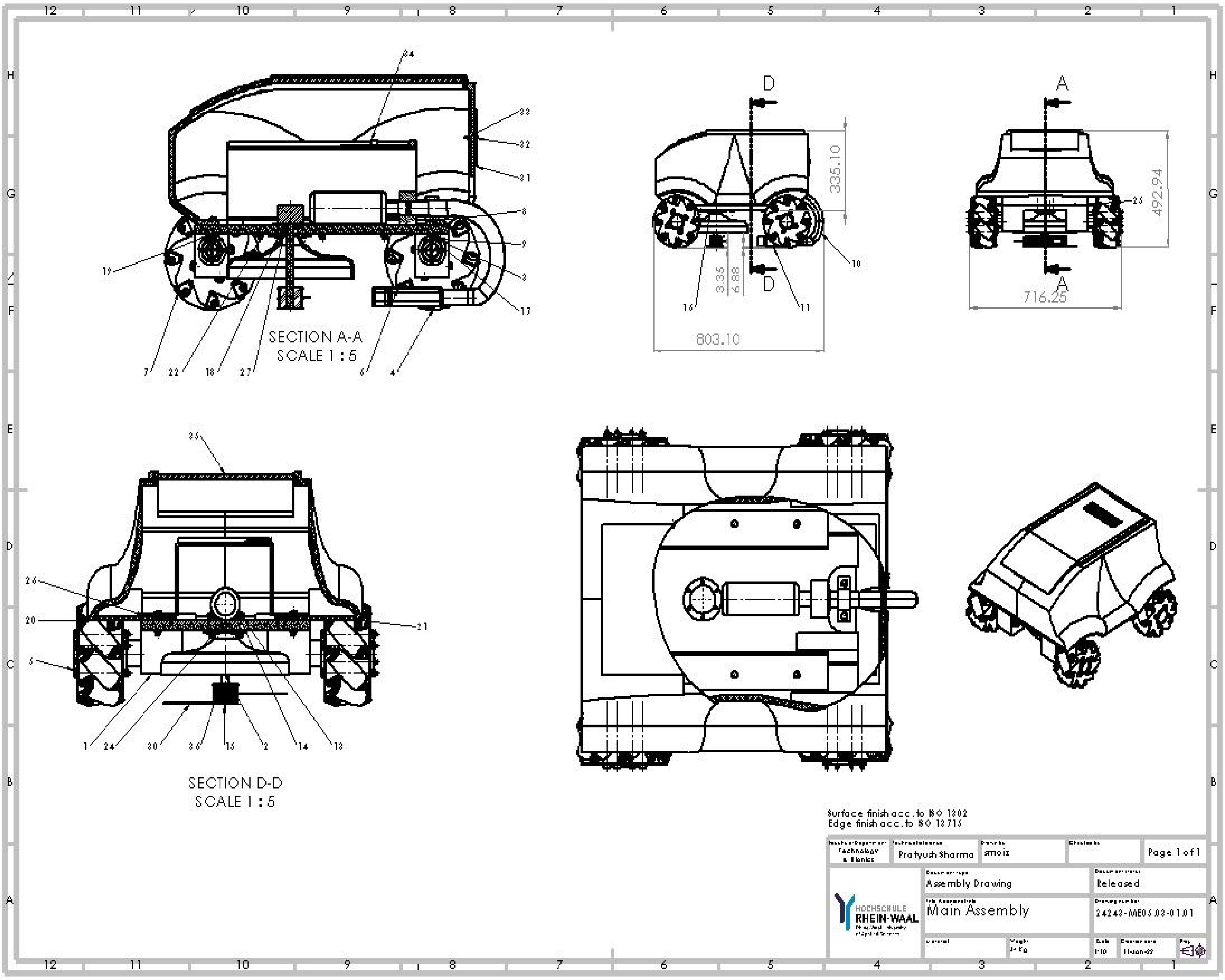
Mecanum wheels

Part	Quantity
Mecanum wheels- Diameter: 40mm	4

Figure 27. Mecanum wheels[]

Technical Drawings

The assembly drawing above shows the entire assembled unit with its Front View, Side View, A Broken-Out Section View and an Isometric View to show the overall dimensions of the Assembly.
The Assembly Drawing and the Partslist (BOM) have also been uploaded separately (with a better resolution) in the group folder.



item	qty.	description	specification	drawing no.	rev.	material
36	1	Central Shaft		24243-ME05.03-01.001.01	0	3003 Alloy
35	1	Housing Top		24243-ME05.03-01.001.01	0	PVC Rigid
34	3	Micro-Controller		24243-ME05.03-01.001.01	0	
33	4	Bolt	DIN EN 24014 - M4 x 25 x 14-S	24243-ME05.03-01.001.01	0	Carbon Steel
32	2	Electrode Bracket		24243-ME05.03-01.001.01	0	AISI 1020
31	2	Electrode		24243-ME05.03-01.001.01	0	
30	2	Upper Nylon Wire		24243-ME05.03-01.001.01	0	Nylon 101
29	1	Bearing Lower Ring	SKF_7003_CD_HCP4AH_18	24243-ME05.03-01.001.01	0	Stainless Steel
28	1	Bearing Upper Ring	SKF_7003_CD_HCP4AH_16	24243-ME05.03-01.001.01	0	Stainless Steel
27	12	Bearing Balls	SKF_7003_CD_HCP4AH_3	24243-ME05.03-01.001.01	0	Stainless Steel
26	1	Shelf 2		24243-ME05.03-01.001.01	0	3003 Alloy
25	1	Battery		24243-ME05.03-01.001.01	0	Lithium ion
24	1	Vacuum Bag		24243-ME05.03-01.001.01	0	Polyurethane Fo
23	1	Vacuum Motor		24243-ME05.03-01.001.01	0	
22	8	Bolt	DIN EN 28765 - M8x1 x 45 x 22-S	24243-ME05.03-01.001.01	0	Carbon Steel
21	1	Mirror Housing Walls (1)		24243-ME05.03-01.001.01	0	PVC Rigid
20	1	Housing Walls (1)		24243-ME05.03-01.001.01	0	PVC Rigid
19	10	Hexagon Nut	ISO 4036 - M8 - S	24243-ME05.03-01.001.01	0	Carbon Steel
18	10	Hexagon Nut	ISO 4036 - M4 - S	24243-ME05.03-01.001.01	0	Carbon Steel
17	2	Bolt	DIN EN 28765 - M8x1 x 40 x 22-S	24243-ME05.03-01.001.01	0	Carbon Steel
16	1	Bolt	DIN EN 24014 - M4 x 35 x 14-S	24243-ME05.03-01.001.01	0	Carbon Steel
15	1	Nylon Holder		24243-ME05.03-01.001.01	0	1.4003 (X2CrNi1
14	1	Cutting Motor		24243-ME05.03-01.001.01	0	
13	1	Cutting Motor Bracket		24243-ME05.03-01.001.01	0	1.4003 (X2CrNi1
12	1	Vacuum Bracket		24243-ME05.03-01.001.01	0	1.4003 (X2CrNi1
11	1	Vacuum Head		24243-ME05.03-01.001.01	0	PP Copolymer
10	1	Vacuum Pipe		24243-ME05.03-01.001.01	0	PVC Rigid
9	48	Nut	DIN EN ISO 10512 - M8x1 - N	24243-ME05.03-01.001.01	0	Carbon Steel
8	48	5-Bolt Corrected		24243-ME05.03-01.001.01	0	1023 Carbon Ste
7	64	4-Roller Bracket Corrected		24243-ME05.03-01.001.01	0	ABS
6	32	2-Roller Corrected		24243-ME05.03-01.001.01	0	Natural Rubber
5	4	3-Shaft Corrected		24243-ME05.03-01.001.01	0	1060 Alloy
4	8	1-Frame Corrected		24243-ME05.03-01.001.01	0	3003 Alloy
3	4	Motor New		24243-ME05.03-01.001.01	0	3003 Alloy
2	1	Cover Corrected		24243-ME05.03-01.001.01	0	1.4003 (X2CrNi1
1	1	1-Base Plate Corrected 2		24243-ME05.03-01.001.01	0	3003 Alloy

Technology & Bionics

Pratyush Sharma

28-02-2020

Pratyush Sharma

HOCHSCHULE RHEIN-WAAL
Rhine-Waal University of Applied Sciences

Partslist

24243-ME.5.2015.03

bill of material

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10-01-2022

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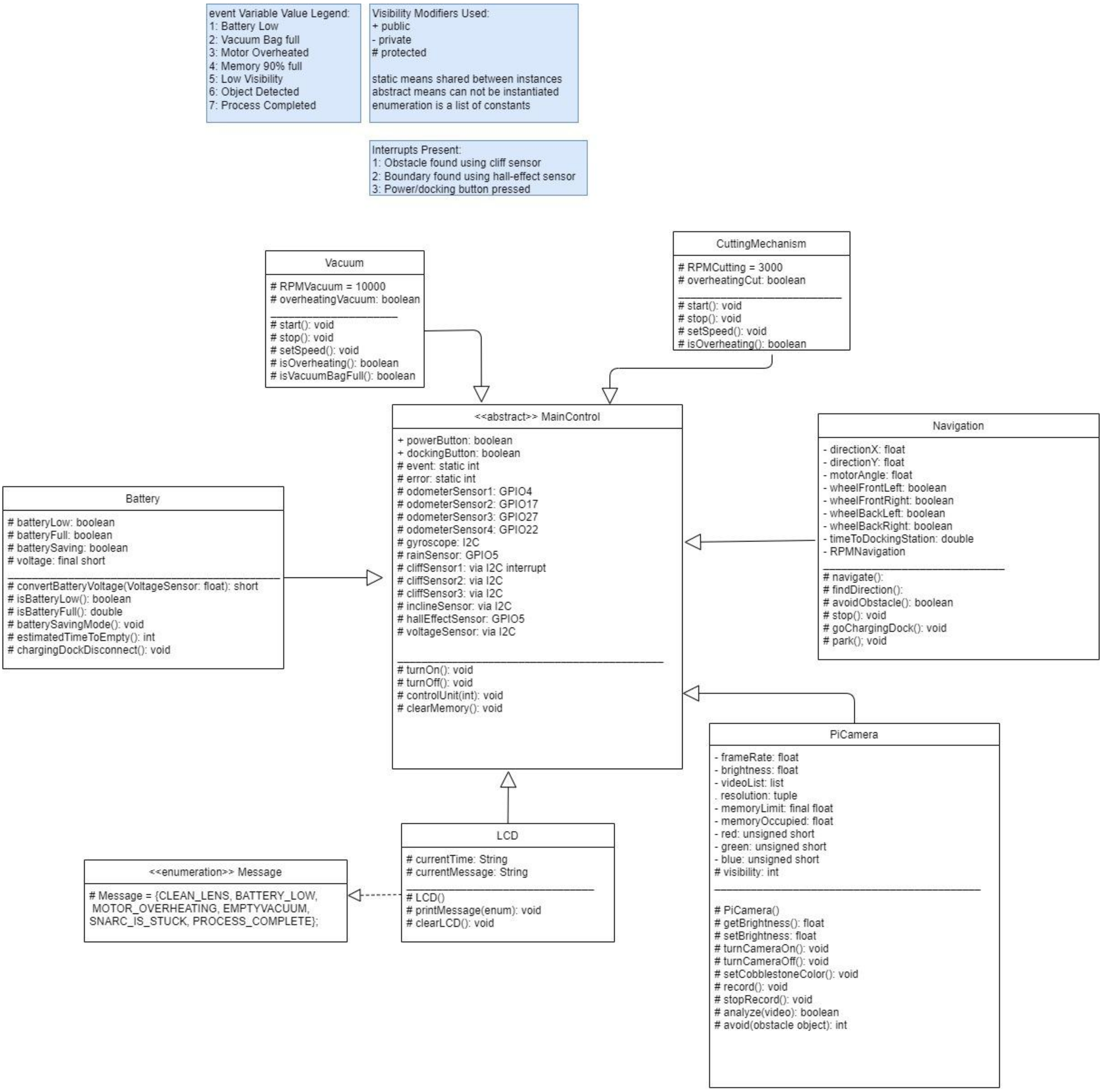
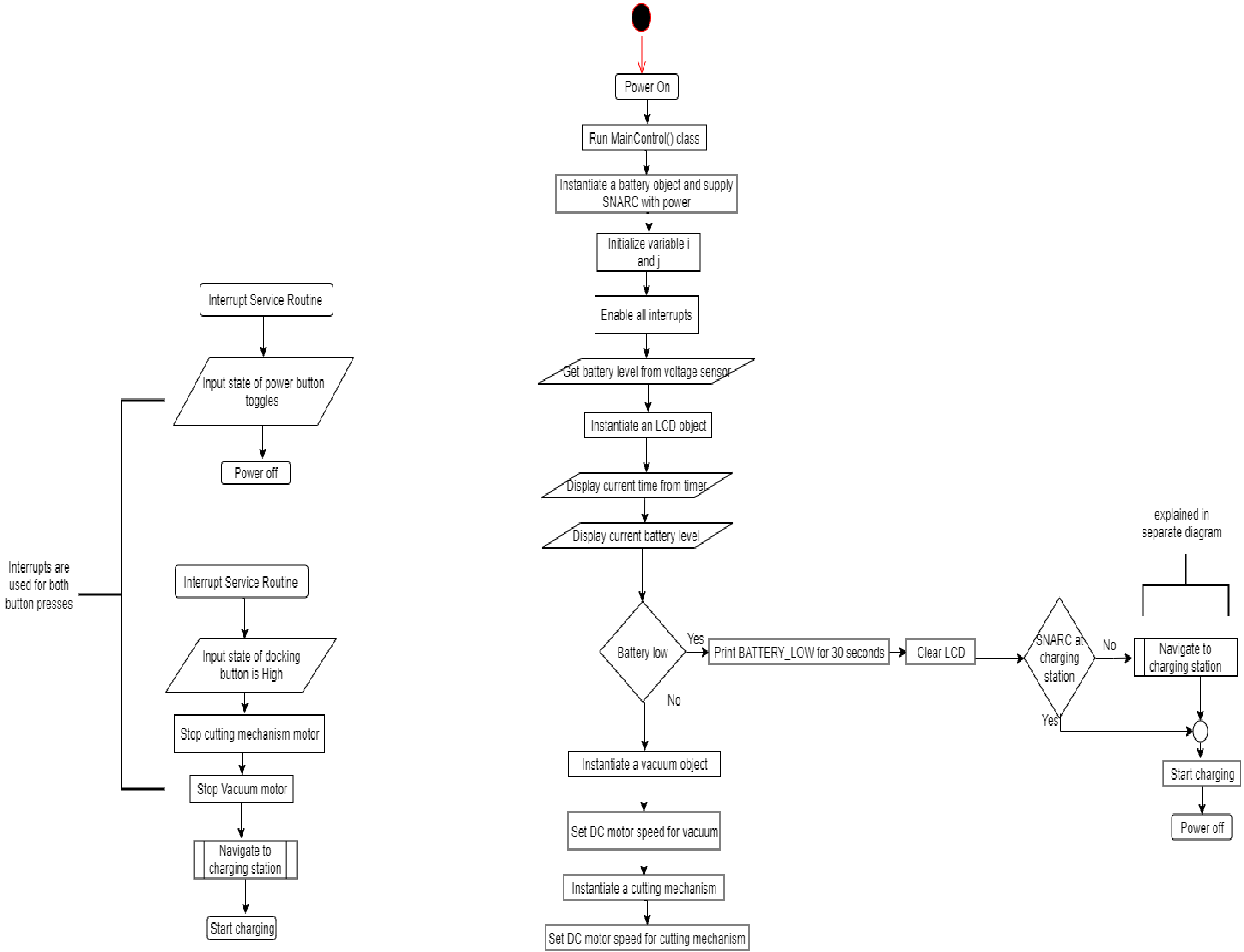
Pseudo Code

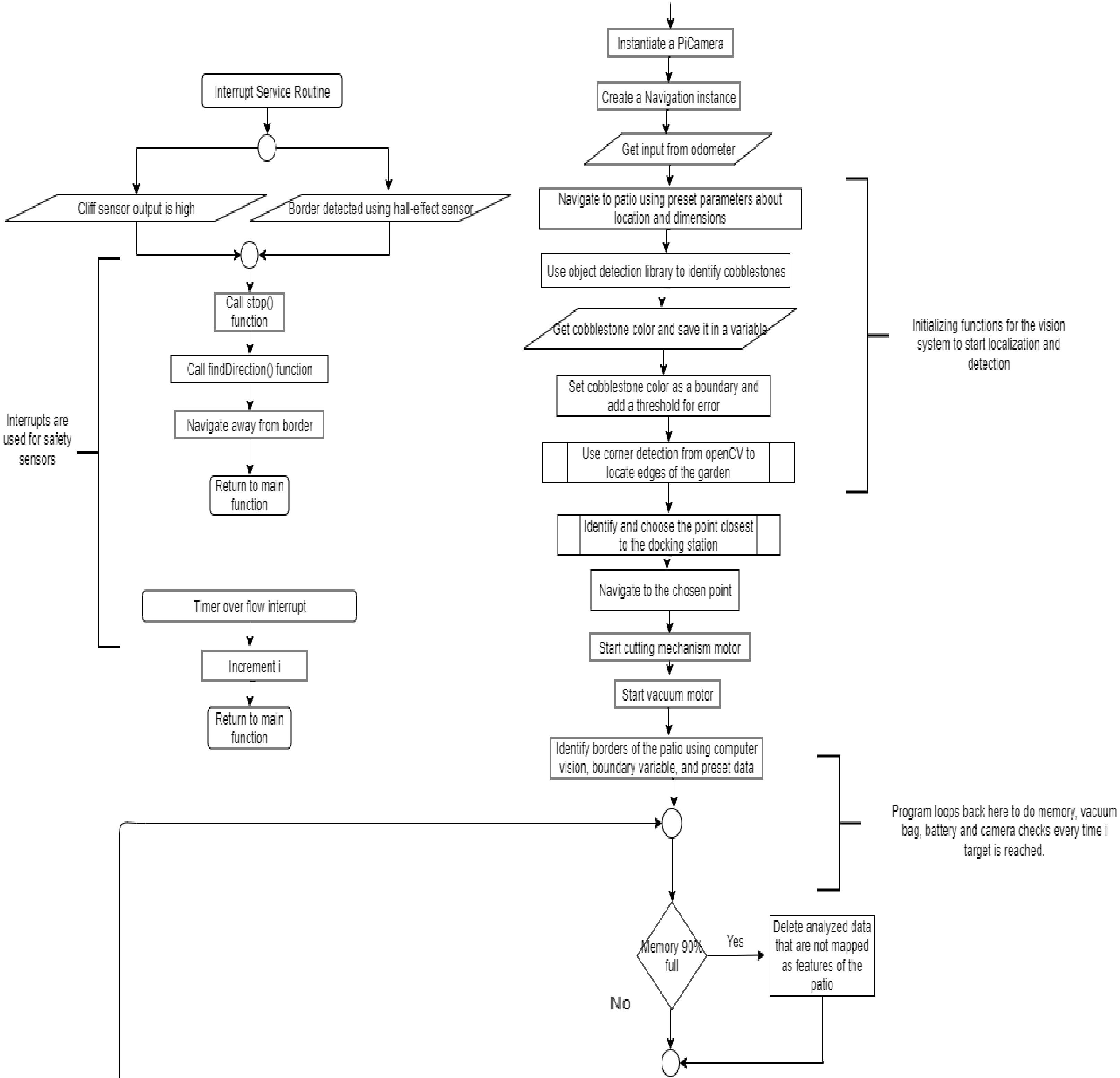
The following UML diagram briefly gives an overview of the programming involved in SNARC. The flow chart then continues to describe the order in which the operations are executed. Upon powering on, instances of the program are instantiated. Periodic checks are done throughout the program to check on the value of the variables used and execute the program accordingly.

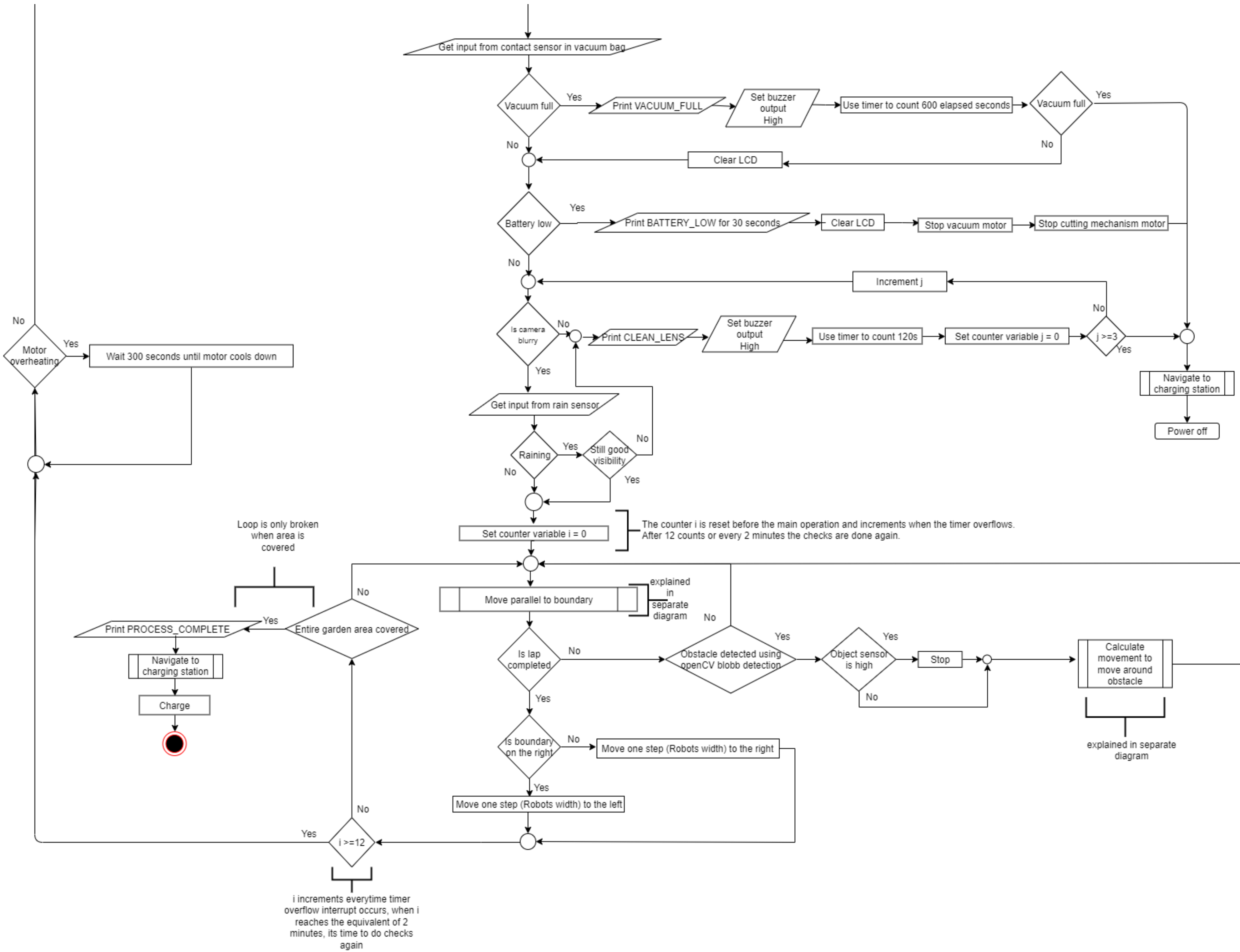
For the main cutting function, the loop is only broken when the garden area is covered or when checks break it. Interrupts are also used for operations which need immediate attention. The main operation is the navigation and the cleaning of the cobblestones, but after a specified amount of time measured with timer overflows, the checks are done again.





Power On
Run MainControl() class
Instantiate a battery object and supply SNARC with power
Initialize variable i and j
Enable all interrupts
Get battery level from voltage sensor
Instantiate an LCD object
Display current time from timer
Display current battery level
Battery low
Yes
Print BATTERY_LOW for 30 seconds
Clear LCD
SNARC at charging station
No
Navigate to charging station
explained in separate diagram
Yes
Start charging
Power off
No
Instantiate a vacuum object
Set DC motor speed for vacuum
Instantiate a cutting mechanism
Set DC motor speed for cutting mechanism
Interrupt Service Routine
Input state of power button toggles
Power off
Interrupts are used for both button presses
Interrupt Service Routine
Input state of docking button is High
Stop cutting mechanism motor
Stop Vacuum motor
Navigate to charging station
Start charging


Interrupt Service Routine
Cliff sensor output is high
Border detected using hall-effect sensor
Call stop() function
Call findDirection() function
Navigate away from border
Return to main function
Interrupts are used for safety sensors
Timer over flow interrupt
Increment i
Return to main function
Instantiate a PiCamera
Create a Navigation instance
Get input from odometer
Navigate to patio using preset parameters about location and dimensions
Use object detection library to identify cobblestones
Get cobblestone color and save it in a variable
Set cobblestone color as a boundary and add a threshold for error
Use corner detection from openCV to locate edges of the garden
Initializing functions for the vision system to start localization and detection
Identify and choose the point closest to the docking station
Navigate to the chosen point
Start cutting mechanism motor
Start vacuum motor
Identify borders of the patio using computer vision, boundary variable, and preset data
Program loops back here to do memory, vacuum bag, battery and camera checks every time i target is reached.
Memory 90% full
Yes
Delete analyzed data that are not mapped as features of the patio
No


Get input from contact sensor in vacuum bag
Vacuum full
Yes
Print VACUUM_FULL
Set buzzer output High
Use timer to count 600 elapsed seconds
Vacuum full
Yes
No
No
Clear LCD
Battery low
Yes
Print BATTERY_LOW for 30 seconds
Clear LCD
Stop vacuum motor
Stop cutting mechanism motor
No
Increment j
No
Is camera blurry
No
Print CLEAN_LENS
Set buzzer output High
Use timer to count 120s
Set counter variable j = 0
j >=3
Yes
Navigate to charging station
Power off
Yes
Get input from rain sensor
Raining
Yes
Still good visibility
No
No
Yes
Motor overheating
No
Yes
Wait 300 seconds until motor cools down
Set counter variable i = 0
The counter i is reset before the main operation and increments when the timer overflows.
After 12 counts or every 2 minutes the checks are done again.
Loop is only broken when area is covered
No
Move parallel to boundary
explained in separate diagram
No
Yes
Print PROCESS_COMPLETE
Entire garden area covered
Navigate to charging station
Charge
Is lap completed
No
Obstacle detected using openCV blobb detection
Yes
Object sensor is high
Yes
Stop
Calculate movement to move around obstacle
No
Yes
explained in separate diagram
Is boundary on the right
No
Move one step (Robots width) to the right
Yes
Move one step (Robots width) to the left
No
Yes
i >=12
i increments everytime timer overflow interrupt occurs, when i reaches the equivalent of 2 minutes, its time to do checks again

Separate Diagrams

The following are the diagrams explaining three predefined processes, denoted as rectangle boxes with vertical lines inside. These are separately described to conserve space in the main flowchart.

Bill of Material (Electronic Components) - Buy Parts

The following electronics were included in the making of SNARC. They range in functionality from supplying power, to controlling the motors for operation as well as for sensing environmental conditions and surroundings. The step-down converters are used to supply the components with the respective required voltage. While the ADC and PWM are for signal processing and control. Some components are also used for the user interface. This includes the LCD, buzzer, and pushbuttons. As well as components that cover more applications.

No.	Component name	Quantity	Estimated Price in €	Vendor name	Link*
1	Raspberry Pi 4	1	30	Shenzhen Zhida Shunfa Electronics	https://tinyurl.com/yvceamvd
2	Battery	1	17	Aleaivy lithium battery store	https://aliexpi.com/rWpS
3	Tilt sensor	1	0.3	CZB6721960	https://aliexpi.com/QXtH
4	Gyroscope/ IMU	1	1.7	S+S+S+store	https://aliexpi.com/wjiZ
5	Rain sensor	1	0.5	YX Electronic Components	https://aliexpi.com/rxOV
6	Cliff sensor	3	8.5	Shenzhen Jubaolai Electronics Co., Ltd.	https://tinyurl.com/4br9fy6v
7	Wheel odometry/ speed sensor	4	4	Shenzhen Qinda Electronics Co., Ltd.	https://tinyurl.com/jmnm2658
8	Hall effect sensor	1	0.5	Co's zoo Store	https://aliexpi.com/Gd76

No.	Component name	Quantity	Estimated Price in €	Vendor name	Link
9	Voltage sensor	1	0.3	Sincere Company Store	https://aliexpi.com/JxsW
10	IR receiver/ transmitter	1	0.3	SZ Aitexm Store	https://aliexpi.com/xrUB
11	ADC converter board	1	3.5	GREAT WALL Electronics Co., Ltd.	https://aliexpi.com/K5vy
12	PWM Add on board	1	10	Adafruit	https://www.adafruit.com/product/2928
13	Pi camera	1	2.5	RazerZONE Store	https://aliexpi.com/486D
14	DC/DC step down 5V	2	5	WindGallopRC Hobby Store	https://aliexpi.com/MMU6
15	DC/DC step down 6v	1	2.2	survy 2014 Store	https://aliexpi.com/mWMH
16	High current Dual motor driver	1	13	CZB6721960 Store	https://aliexpi.com/Ed1k
17	Dual motor driver for wheels	2	7.6	Shop911412022 Store	https://aliexpi.com/3sxM
18	DC Motors for wheels	4	13	SeeSensor store	https://aliexpi.com/BDVV

No.	Component name	Quantity	Estimated Price in €	Vendor name	Link
19	DC Motor for blades	1	12	AZ Giant Global store	https://aliexpi.com/Xlma
20	DC Motor Vacuum	1	16	Changzhou Modar Intelligent Technology Co.ltd.	https://tinyurl.com/3a6uafxs
21	Standard microcontroller	1	5.4	Shenzhen Chipskey Technology Co., Limited	https://tinyurl.com/2p9x8z4m
22	LCD Screen	1	1.8	Shenzhen Kingsguar Electronics Co., Ltd.	https://tinyurl.com/ypzerxta
23	Pushbutton	2	0.74	Advanced Tech	https://aliexpi.com/kIsl
24	Buzzer	1	0.5	TENSTAR Store	https://aliexpi.com/zpkd
25	Wires*	-	1	GCsupermarket Store	https://aliexpi.com/VYWL
Total Price (Exclusive VAT) [€]					157.34
Value Added Tax (VAT) [€] (19%)					29.89
Total Price (Inclusive VAT) [€]					187.235

****Wires can be soldered to the board connections so they remain stable during operation. The components are already fixed in grooves on the chassis for stability.***

****The tiny url links sometimes direct to Alibaba homepage. It could be needed to try multiple times.***

Bill of Material (Mechanical Components) - Buy Parts

The following table shows the mechanical parts and machine components used in SNARC. This includes, but is not limited to the nuts and bolts, the cutting mechanism and a cover for it, the wheels and the chassis. It also includes shafts, and the materials for the vacuum. These parts are divided into buy and make parts and are sorted into their tables accordingly.

No.	Component name	Quantity	Estimated Price in €	Vendor name	Link
1	Bolt DIN EN 28765 – M8 X 1 X 45 X 22-N	10	0.09	Shanghai G&T Industry Co., Ltd.	https://tinyurl.com/2p8py6uz
2	Bolt DIN EN 24014 – M4 X 35 X 14-N	10	0.09	Shanghai G&T Industry Co., Ltd.	https://tinyurl.com/2p8py6uz
3	Hexagon Nut ISO 4036 – M8 – N	10	0.09	Wenzhou Jianrui Hardware Technology Co., Ltd.	https://tinyurl.com/5pr7bdb3
4	Hexagon Nut ISO 4036 – M4 – N	10	0.624	Jiaxing Myway Metal Co., Ltd.	https://tinyurl.com/2p8bfxkj
5	Bearing DIN 625 – 6008 – 16,SI,NC, 16_68	5	0.9795	Linqing Zheying Bearing Co., Ltd.	https://tinyurl.com/yy3fpnmu
6	Nylon Wire	0.5 meter	0.01485	Dongguan Zhongshuang Electronic Technology Co., Ltd.	https://tinyurl.com/3e95spb3

No.	Component name	Quantity	Estimated Price in €	Vendor name	Link
7	Mecanum Wheel	4	3.9	Shenzhen Bxf Electronic Technology Co., Ltd.	https://tinyurl.com/ye2x256j
Total Price (Exclusive VAT) [€]					5.78835
Value Added Tax (VAT) [€] (19%)					1.099
Total Price (Inclusive VAT) [€]					6.888

Bill of Material(Mechanical Components) - Make Parts

No.	Component	Quantity	Weight [kg]	Material	Price [€/kg]	Total price [€]*
1	Hub Wall	2	7	PVC-R	0.48	6.72
2	Chassis	1	14	3003 Aluminum Alloy	1.90	26.6
3	Hub Cover	1	2	PVC-R	0.48	0.96
4	Shafts	5	1	3003 Aluminum Alloy	1.90	9.50

No.	Component	Quantity	Weight	Material	Price	Total price [€]
5	Funnel	1	0.072	Propylene	0.83	0.06
6	Vacuum Pipe	1	0.053	PVC-R	0.48	0.0254
7	Vacuum Bag	1	~	Cloth		
8	Vacuum Pipe Bracket	1	0.323	Stainless Steel 1.4003 (X2CrNi12)	1.15	0.37
9	Cutter cover	1	4	Stainless Steel 1.4003 (X2CrNi12)	1.15	4.6
10	Nylon Wire holder	1	0.618	Stainless Steel 1.4003 (X2CrNi12)	1.15	0.711
11	Shelf	1	4	Aluminum Alloy 3003	1.90	7.6
Total Price (Exclusive VAT) [€]						57.1464
Value Added Tax (VAT) [€] (19%)						10.8578
Total Price (Inclusive VAT) [€]						68.0042

**** Total price [€] = Quantity * Weight [kg] * Price [€/kg]***

Production Planning

Overall equipment effectiveness (OEE)

OEE is a measure of the actual productivity of manufacturing processes. Must range between [0 .. 1].

$$OEE = performance\ factor * quality\ factor * availability\ factor$$

Each element ranges from 0 to 1.

List of values used in OEE calculations:

Shift working hours	8 hours
Number of shifts	1.5 shifts
Employee break	30 minutes
Non productive time	60 minutes
Units produced rate	Unit per 1.2 minutes
Total units per day	545 Units
Quality assurance units	15 Units

Performance factor:
The target is to produce 545 units per day, while 560 are planned to be built.

$$Performance\ factor = 545 / 560 = 0.97$$

Quality factor:
15 units out of 545 could be defected.

$$Quality\ factor = (545 - 15) / 545 = 0.97$$

Availability factor:
The time lost due to break hours and nonproductive time in the shift and half shift is around 90 minutes while the expected is 720 minutes.

$$Availability\ factor\ =\ (720\ -\ 90)\ /\ 720\ =\ 0.88$$

$$\mathbf{OEE} =\ 0.97\ *\ 0.97\ *\ 0.88 \approx 0.83$$

Capacity Calculations

Target volume

The planned target production volume is around 150000 units per year by average selling quantity 12500 monthly—five hundred forty-five (545) + 7 (safety factor) units daily depending on average working days around 23 days . One and a half shift (12 hrs). So, the production target volume per month is 12696 units including a 196 units stock as safety factor.

Takt Time

Takt time is the time required per unit to fulfill the customer's needs or wants. The plan is to run one and a half shifts. Twelve hours per day, so at least 45 units per hour need to be produced.

$$Takt\ Time\ =\ 12\ hours/\ 545\ units\ per\ day\ =\ 0.022\ hour/unit\ or\ 1.32\ min/unit$$

Required Technologies

The number of machinery needed to make that goal a reality depending on the production plan can now be determined. The type of machines needed and their requirements of each device have been selected as the engine most suited for the manufacturing of each "make" part.

Part Name	**Processes**		**Time required to produce one unit**
Chassis	CNC - Milling		10 min
Hub Wall	Injection Molding		15 sec
Hub Wall Mirrored	Injection Molding		15 sec
Hub Cover	Injection Molding		15 sec
Shaft	Turing (Lathe)		8 min
Vacuum Funnel	Injection Molding		15 sec
Vacuum Pipe	Extrusion Blow	Heat Induction Bending	25 sec
Vacuum Bag	Cutting	Stitching	15 sec
Vacuum Pipe Bracket	CNC - Milling		5 min
Cutter Cover	Turing (Lathe)	Drilling	6 min
Shelf	Sheet Metal Folding	Drilling	2 min

Time per piece

Consequently, knowing the time for each making process for each component is essential to calculate the number of machines needed. Setup time is not that important in the capacity computations due to the absence of product varieties.

Part Name	Required Machine(s)	Setup Time	Processing Time
Chassis	CNC Milling Machine	2 min	10 min (Bottle Neck)
Hub Wall	Injection Molding Machine	20 min	15 sec
Hub Wall Mirrored	Injection Molding Machine	20min	15 sec
Hub Cover	Injection Molding Machine	20 min	15 sec
Shaft	Lathe Machine	3 min	8 min
Vacuum Funnel	Injection Molding Machine	2 min	15 sec
Vacuum Pipe	Extrusion Blow Machine	1 min	15 sec
	Heat Induction Bending Machine	5 min	10 sec
Vacuum Bag	Cutting Machine	30 sec	5 sec
	Stitching Machine	30 sec	10 sec
Vacuum Pipe Bracket	CNC Milling	2 min	5 min
Cutter Cover	Lathe Machine	3 min	5 min
	Drill Machine	1 min	1 min
Shelf	Sheet Metal Folding Machine	1 min	1 min
	Drill Machine	1 min	1 min

Number of Units produced—before considering OEE

Calculated workload needed for each part based on the number of parts produced, production time for one element. Again, setup *time is not that important in capacity computations due to the absence of product varieties.* Hourly bases to ease the calculations. The setup time will not play a significant role in injection molding-1 because three batches for the three parts per day will be rotated while each utilizes only around 20 % of the machine.

Part	Required Amount created [units/ hr]*	Set up Time	Process Time	Processes**	Total time in minutes***	Actual amount Produced [units/ hr]
Chassis	46	2 min	10 mins	CNC Milling – 1	60	60
Hub wall	46	20 min	15 sec	Injection Molding – 1	12	48
Hub wall mirrored	46	20 min	15 sec	Injection Molding – 1	12	48
Hub Covers	46	20 min	15 sec	Injection Molding - 1	12	46
Shafts	230	3 min	8 mins	Lathe machines - 1	60	233
Funnels (Vacuum)	46	2 min	15 sec	Injection Molding – 2	12	48
Pipe (Vacuum)	46	5 min	15 sec	Extrusion blow	20	48
		1 min	10 sec	Heat Induction Bending		
Vacuum Bags	46	1 min	5 sec	Cutting	12	48
		1 min	10 sec	Stitching		
Vacuum Pipe Bracket	46	2 min	5 min	CNC milling - 2	60	48
Cutter Cover	46	3 min	5 min	Lathe - 2	60	48
		1 min	1 min	Drilling		
Shelf	46	1 min	1 min	Sheet Metal Folding	46	46
		1 min	1 min	Drilling		

***The values in this column to reach the production target at the end of the day*.**

*****There are two different CNC Milling machines, injection molding, and lathe machines.***

*******The total time in minutes relates to the time a machine runs in 1 hour*.**

Number of machines needed —Considering OEE

Calculation of the number of machines required depends on the daily working hours (one and a half shifts = 12 hours) and the number of parts produced per hour (capacity of each machine) in addition to the actual required production amount per day after consideration of OEE.

Parts	Machine Type	Time per piece	Number of Machines	Number of Machines ÷ OEE (= 0.83)
Chassis	CNC Milling – 1	10 mins	7.67	9.24
Hub wall	Injection Molding – 1	15 sec	0.19	0.23
Hub wall mirrored	Injection Molding – 1	15 sec	0.19	0.23
Hub Covers	Injection Molding - 1	15 sec	0.19	0.23
Shafts	Lathe machines - 1	8 mins	30.67	36.95
Funnels (Vacuum)	Injection Molding – 2	15 sec	0.19	0.23
Pipe (Vacuum)	Extrusion blow	15 sec	0.19	0.23
	Heat Induction Bending	10 sec	0.13	0.15
Vacuum Bags	Cutting	5 sec	0.06	0.08
	Stitching	10 sec	0.13	0.15
Vacuum Pipe Bracket	CNC milling - 2	5 min	3.83	4.61
Cutter Cover	Lathe - 2	5 min	3.83	4.61
	Drilling	1 min	0.77	0.92
Shelf	Sheet Metal Folding	1 min	0.77	0.92
	Drilling	1 min	0.77	0.92

Total number of machines needed —after consideration of OEE

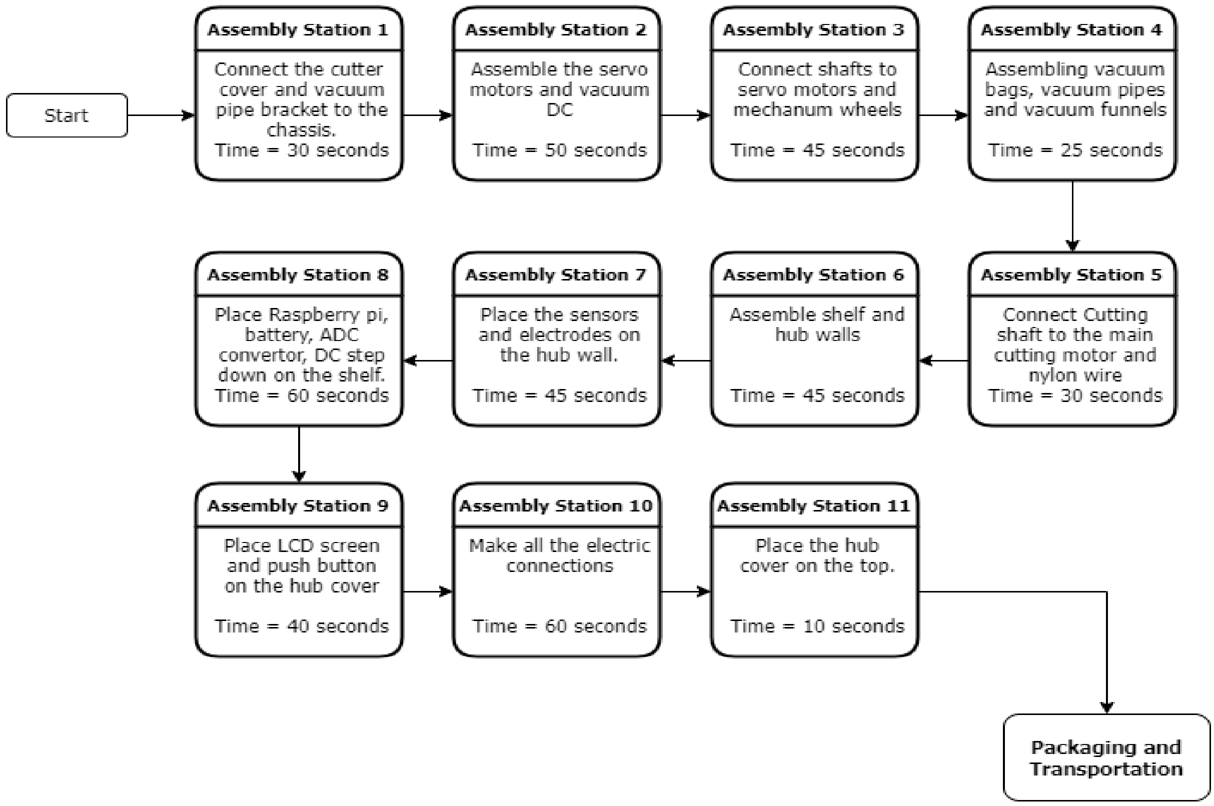
Machine Type	Total number of machines (calculated)	Total number of machines (rounded)
CNC Milling – 1	9.24	10
Injection Molding – 1	0.69	1
Lathe machines - 1	36.95	37
Injection Molding – 2	0.23	1
Extrusion blow	0.23	1
Heat Induction Bending	0.15	1
Cutting	0.08	1
Stitching	0.15	1
CNC milling - 2	4.61	5
Lathe - 2	4.61	5
Drilling	1.84	2
Sheet Metal Folding	0.92	1

Requirements of Machines

No.	Machine	Requirements
1	Injection Molding	● Able to accommodate a mold with generous cavity (800 mm x 300 mm x 500mm)
2	CNC Milling Machine	● Minimum X and Y travel 600 mm ● Minimum Z travel 60 mm ● Able to mill Aluminum ● Minimum RPM 15000 ● Good Precision
3	Lathe Machine	● Minimum RPM 1000 ● Precision upto 0.01 mm
4	Drilling Machine	● Work Range 1200 mm ● Table Size 600 mm x 900 mm
5	Extrusion Blow Machine	● Mold Moving Stroke 370 ● Clamping force 44kN ● Air Pressure 0.6 Mpa
6	Heat Induction Bending	● Motor Power at least 20kw
7	Cutting Machine	● Cutting Speed 1200mm/s ● High Accuracy
8	Stitching Machine	● Able to sew at least 30 mm ● Stitch length more less than 7 mm
9	Sheet Metal Folding	● Width of table at least 1500 mm ● Nominal pressure more than 1000kN

Assembly Sequence

In order to facilitate quick assemblies, all components will be manufactured simultaneously in order to match the assembly steps below. The number of assembly labors were approximated by making the assumption that every station needs at least 1 employee. The stations that have relatively complicated tasks have 2 employees.



Number of Production Labors

Assembly labors needed

Station 1	1	Station 7	1
Station 2	2	Station 8	2
Station 3	1	Station 9	1
Station 4	1	Station 10	1
Station 5	1	Station 11	1
Station 6	1	**Total**	13

Manufacturing labors needed

Stations	**Number of labors**
CNC Milling – 1	4
Injection Molding – 1	2
Lathe machines - 1	6
Injection Molding – 2	2
Extrusion blow	1
Heat Induction Bending	1
Cutting	1
Stitching	1
CNC milling - 2	2
Lathe - 2	2
Drilling	1
Sheet Metal Folding	1
Total	24

Cost Calculation

Buy part costs

Components (Buy Part)	Cost [€/unit]
Mechanical Buy Parts	6.888
Electrical Buy Parts	187.235
Total	194.123

Machinery Costs

Machine	Quantity	Cost per machine [€/machine]	Link*
Injection Molding	2	4,461.17	https://tinyurl.com/5jeaunsr
CNC (Milling)	15	39,615.19	https://tinyurl.com/ycyuzuyu
Drilling	2	443.77	https://tinyurl.com/yc372dtk
Turning (lathe)	42	1,516.80	https://tinyurl.com/2p83j6ce
Extrusion blow machine	1	16,951.56	https://tinyurl.com/2p9xt78t

Machine	Quantity	Cost per machine [€]	Link
Heat Induction Bending	1	17,844.68	https://tinyurl.com/yrbbe8ub
Cutting	1	14,721.87	https://tinyurl.com/3uejswv2
Stitching	1	892.24	https://tinyurl.com/bdzjycks
Sheet metal folding	1	5,353.41	https://tinyurl.com/5n77z7ef
Total Price (Exclusive VAT) [€]		723,507.10 €	
Value Added Tax (VAT) [€] (19%)		137,466.35 €	
Total Price (Inclusive VAT) [€]		860,973.45 €	

The tiny url links sometimes direct to Alibaba homepage. It could be needed to try multiple times.

Depreciation cost

By applying a fully linear depreciation method for 10 years.
That gets,

Annual depreciation cost =

$$860973.45\ € \ /\ 10 \ =\ 86097.35\ €$$

Depreciation cost per month =

$$86097.35\ /\ 12 \approx 7174.78\ €$$

Depreciation cost per unit =

$$7174.78\ /\ 12696 \approx 0.57\ €$$

Machine-dependent manufacturing overheads

The expenses for maintenance and repairs are considered to be 5% of machine investments per year. Accordingly :

$$5\%\ of\ 86097.35\ € \approx 4304.87\ € \ /\ year$$
$$4304.87\ €/\ 12 \approx 358.74\ €\ /\ month$$

Consequently, the expenses for maintenance and repairs per unit can now be calculated.

$$358.74\ €\ /\ 12696 \approx 0.03\ €$$

Tools and supplies per unit are considered to be 5% of machine investments per year

$$358.74\ €\ /\ 12696 \approx 0.03\ €$$

So, The **total machinery cost per unit** can now be calculated.

$$€\,0.57\ +\ €\,0.03\ +\ €\,0.03\ =\ €\,0.63$$

Direct labor Costs

The average factory labor salary in Germany is taken to be on average 2600 euros. [53] The following is a summary of the number of laborers required.

Production labor	24
Assembly labor	13
Total Number of labors	37

This makes the direct labor cost :

$$37\ labors\ *\ 2600\ €\ *\ 1.5\ shifts\ =\ 144300\ €/\ month.$$

The **direct labor cost per unit** becomes

$$144300\ €\ /\ 12696\ =\ 11.37\ €$$

The total **make parts cost** is summarized in the table below:

Raw Material	68.01 €/unit
Machinery cost	0.63 €/unit
Direct labor cost	11.37 €/unit
Manufacturing overhead (40 % from labor cost)	4.54 €/unit
Total	84.55 €/unit

Rental Cost

The factory layout is designed to be workshops for manufacturing and assembly lines. The area is listed below:

Storages	200 m²
Production	350 m²
Assembly	180 m²
Supervisor's and employees	80 m²
Car park lot and space for trucks	2000 m²
Total Space	2810 m²

Rental price outside the city is average 5 €/m² [52]. So, total rental price = 14050 € / month.

The **Rental Cost per unit** then is:

$$14050€ / 12696 = 1.11 €$$

Electricity Cost

To calculate approximate electricity costs, the requirements for machines will be added to the electricity costs of the factory space. The main assumption is that all machines would be running at full rated power.

The machines are planned to be running for 12 hours per day. The following calculations state the power requirements in kWh for each machine as these will use the bulk of the electricity supply.

An example calculation for one machine is shown below, the rest of them are summarized in the table.

Injection molding machine has a rated power of 11kW according to its hyperlink in the machinery costs section, so :

$$11kW * 12h = 132kWh$$
$$132kWh * 2 = 264kWh$$

Where 2 is the total quantity of the machines used in this case.

Similarly the electricity requirements for the rest of the machines were also calculated. The table shows the final results.

Machines	**Electricity requirements in kWh**
Injection molding	264
CNC (Milling)	3330
Drilling	13.2
Turning (lathe)	554.4
Extrusion blow machine	366
Heat Induction Bending	264
Cutting	132
Stitching	9
Sheet metal folding	132
Total :	5065 kWh

A typical non-residential building energy consumption per m² is reported to be around 250kWh per year. [51]

The total approximate factory space is 2810 m². Consequently :

$$250kWh/m^2 * 2810m^2 = 702500kWh$$

$$702500kWh/365 = 1925kWh$$

The total approximate electricity requirements then are the sum of the machine and factory requirements.

$$Total\ kWh = 5065 + 1925 = 6990kWh$$

The reported cost of electricity in Germany for industries is 0.1825 €/ kWh [50] This allows to calculate the cost of electricity per month:

$$6990\ kWh * 0.1825€ * 23\ days = 29340.53€/\ month$$

Finally the **cost of electricity per unit** can be calculated

$$29340.53€ / 12696 = 2.31\ €$$

The following table shows the total **Cost of Goods Manufactured** achieved this way:

$$194.123\ € + 84.55\ € + 1.11\ € + 2.31\ € = 282.09\ € / Unit$$

Module	**Cost in € / unit**
Buy parts	194.123
Make parts	84.55
Rental costs	1.11
Electricity costs	2.31
Cost of total goods manufactured	282.09

Overheads

The administration Costs are 10% of the costs of goods manufactured : 28.21 €
The marketing Cost are 5% of cost of goods manufactured : 14.10 €
The R&D Costs are 5% of cost of goods manufactured) : 14.1 €

The sales related costs have the assumption that 10 people are employed. The average salary of each employee is 2600 € monthly.
The Sales cost per unit can now be calculated:

$$(10 \ * \ 2600€) \ / \ 12696 \, units \ = \ 2.05 \, €$$

Final calculations

The following table shows the final calculations to achieve the total price of the machine.
The price is calculated this way :

$$282.09 \, € \ + \ 28.21 \, € \ + \ 2.05 \, € \ + \ 14.10 \, € \ + \ 14.10 \ \approx 340.55 \, €$$

Module	**Cost in € / unit**
Cost of total goods manufactured	282.09
Administration costs (10%)	28.21
Marketing Cost (5%)	14.10
R&D Costs (5%)	14.10
Sales cost per unit	2.05
Total Cost per unit	340.55

Turnover

Earning Before Interest and Tax (Ebit) = Sales Revenue - Total cost
= 499 € - 340.55 € ≈ 158.45€ / unit.

Earning Before Interest and Tax (Ebit) = 158.45 €/unit * 150000 unit/year
= 23767500 €

Conclusion

To summarize everything, to achieve the ambitious target of selling 150,000 units in one year, many different things had to be taken into account with input from various different fields of engineering.
In the beginning, it was important to set realistic organizational targets and that was done in the Work packages section. Although the work was sometimes off the exact calculated pace, in the end the final deadlines were achieved. In the Market decisions section, the outlined price range of 499 € - 799€ defined the goal of the project.

According to the requirements manual and the make or buy decisions, it was outlined clearly the machines and components needed for SNARC. This allowed for the creation of the Bill of Materials and Technology selection.

Finally, the Production planning and Cost calculation solidified the fact that the target sale price can be achieved within the pre-specified range. The final calculations included a few assumptions such as average salaries and workers required; however, the final number was still well below the sale price, meaning that the profits were still hefty.

In the end, as a personal review of the project, the milestone limits induced a need to learn how to better research and learn under time pressure. However, it goes without saying that the potential of SNARC would be more richly fulfilled if a longer time frame was available for research.
Nevertheless, it must be said that it was indeed a great learning experience and hopefully the document was educational, compact and up to the required standards.

Thank you for reading.

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