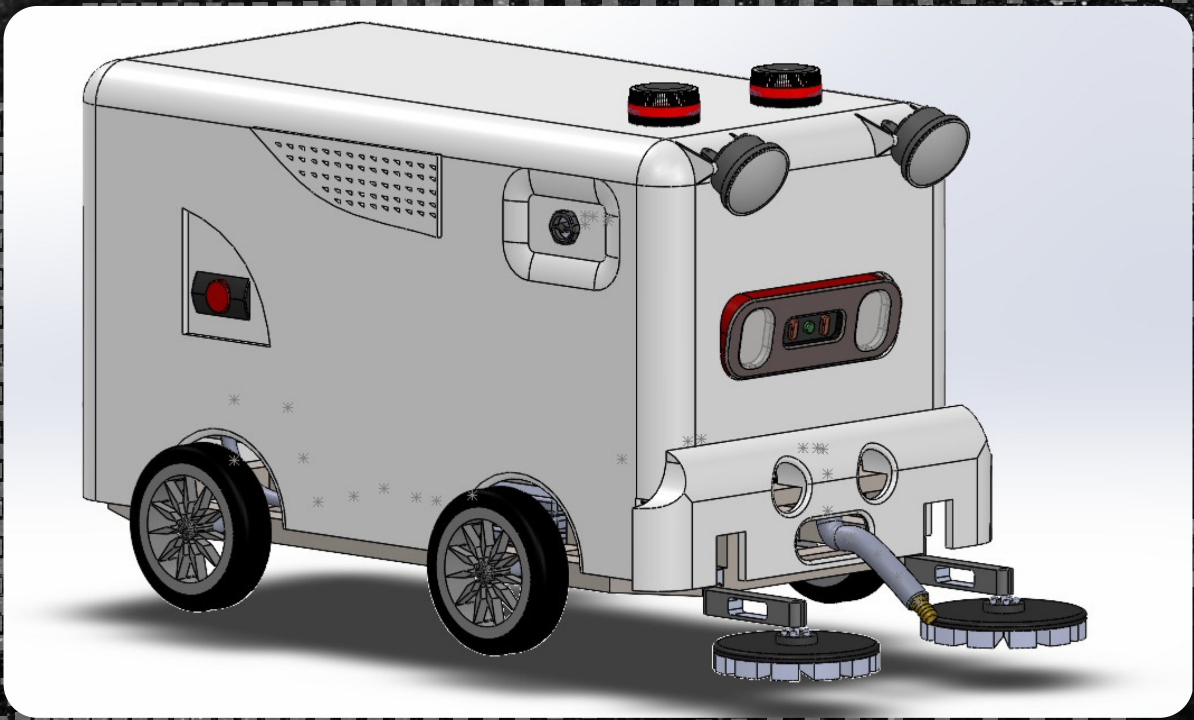
UNIVERSITI TEKNOLOGI MALAYSIA

PRODUCT INNOVATION DEVELOPMENT

Roadside Drain Cleaner



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1. INTRODUCTION

1.1 Background

In the list of natural disasters affecting the Malay peninsula, with far reaching effects causing massive structural damage and forcing residents to flee their houses in hopes of refuge. However, environmental estimates indicate that Malaysia's overall rainfall has increased by a factor of 15 percent within the last 40 years [1]. This implies that the chances of floods is higher than ever before. The primary safeguard against such floods are dams, storm drains and other facilities that work to distribute the water and allow low-altitude sectors of the country to displace large amounts of water in attempts to prevent stagnant pools and further flooding. Within these safeguards, the primary and perhaps most overlooked are the roadside drains that allow roads and highways to be clear.

1.2 Problem Statement

The objective of this study is to create an autonomous device that is capable of effectively clearing any drainage blockage and collecting litter to ensure cleanliness and functionality of road side drains. Furthermore, this device should not use any traditional source of power (diesel, petrol etc.) and should be self-sufficient in this regard. Overall, the device must be easy to maintain, and should also comply with Malaysian road design standards to ensure its function and prevent further flooding.

2. PDS (Product Design Specification)

Target product design specification (PDS) is fundamentally the requirements and demands of the customer - whether internal or external - that are expected from the product (Kent, 2016). Upon thoroughly extracting and analyzing the project briefing as it is the source of customer statements, the appropriate need statements were formed. Hence, these need statements were elaborated and prioritized into primary, secondary and tertiary need statements. The result of that process ultimately governed our development of the PDS criteria.

2.1 Needs Identification

There were four main points that stood out to matter the most to the customer. Firstly, the customer expressed the high effort and time that was required of the current drain cleaning and unclogging system. Consecutively, the customer added the significant dependance of the processes on manual labor. This issue seemed to have been the root of the following customer complaints on the current system. The high cost of workers' wages coupled with the human nature of declining efficiency and performance were described as major contributors to most of the issues that fuel the need for change. The need statements resulting from the aforementioned customer statements are presented in the following table.

Customer Statement	Need Statement
"Current system requires extensive scheduling"	New system has autonomous ability to support solo/pilot function
"Current system is too costly"	New autonomous system is low cost
"Solely dependant on humans to clean, collect road side litter and remove blockage"	New system is capable of cleaning, collecting rubbish and maintaining drainage systems
Roadside drainage needed to convey rainwater and prevent floods"	New system effectively clears blockages to prevent flooding

Table. Main customer statements interpreted into need statements.

In order to meet the needs of the customer, several prerequisite functions must be achieved. For instance, the autonomous operation of the new system assumes the possible inclusion of machine learning or artificial intelligence into the system. This ensures it requires minimal - near zero - scheduling and managing effort from the user in regular operation (excluding periodic maintenance operations). The following list shows the branching of the 5 main needs - which were derived from the customer statements - into more tangible strategic (primary), tactical (secondary) and operational (tertiary) needs along with hiddens ones that are worth pointing out.

Categorized need statements:

- Need: New system has autonomous ability to support solo/pilot function

  * New System has to be easy to set up. Requiring little to no effort to manage and operate

* New system can utilize artificial intelligence to better understand the user

** New system has built in processing unit to implement machine learning

- Need: New autonomous system is low cost

* New system is easy and affordable to maintain - requires minimal maintenance.

* New system is reliable.

*** New system uses durable materials to last longer and be more sustainable

- Need: New system is capable of cleaning, collecting rubbish and maintaining drainage systems

* New system is effective and energy efficient.

** New system uses effective tools and techniques to clear rubbish and unclog drainage systems

* New system does not require human supervision

** System can be trusted to operate perfectly

!*** New system will notify in case of issues.

- Need: New system effectively clears blockages to prevent flooding

* New system can identify flooded areas and resolve them immediately and effectively.

* New system can work in highly unclean and challenging conditions.

*** New system can finish the job in one go, effectively.

The organized needs shown above act as a guideline to the upcoming research that will be done as part of the information gathering process in product development; hence produce the design specifications document. It must be noted that the PDS text is kept amenable along the concept generation and selection process as more factors become clearer the further the project progresses.

2.2 Information Gathering

Innovation does not mean to generate a completely alien idea; but often, it involves plenty of influence from various areas. Collecting information is necessary to be able to better understand the needs of the customer and realize the way other people have approached the same problem. In most cases, the widely known solution to a common problem is the result of many generations of engineers attempting to improve on the same core concept.

In our case, upon observing drain cases of drain blockage followed by succinct research on the primary causes for blockage in road drains, the accumulation of litter and inevitable blockage of the drains' opening as a result was found to be the culprit. According to multiple online sources, there are two scopes of the flooding issue that can be targeted in order to minimize or completely eradicate it: the macro and micro level. The large scale side of the equation was deemed to be out of scope for our case as it mostly involves other methods of solving the issue. In our case, as aforementioned in the problem statement, the main focus is on the micro level - attending to flooding at the drains by maintaining them free of litter that causes the blockage. Moreover, the speed at which the water flows into the drainage system - causing flooding in areas with already compromised and obsolete drain designs - was reported to test and fail most drain systems in Malaysia as they are pushed to their design limits. Conclusively, considering the extremely high cost of implementation of new drainage systems at an infrastructure scale and the focus of this project on the replacement of the current manual labor maintenance system; the simple autonomy of the litter cleaning and drain unblocking processes are believed to meet the customer needs. The pre-existence of road cleaning vehicles has largely inspired the concept generation and selection process; as it serves the same purpose but lacks the equipment to unclog drains.

2.3 Design Specification

Following the research on the flooding problem - looking into the roots of the problem and exploring current solutions that were proven to be effective in cleaning rubbish from roads - the design specifications of the solution outlines 3 main requirements.

- Able to work autonomously without any need for guidance.
- Able to collect litter and clear roadside garbage
- Able to maintain roadside drainage systems

Moreover, the PDS document (see Appendix) included various aspects that accompany the statements above. These aspects are categorized as the product material selection, expected performance, reliability (life span and required effective quantity), physical requirements, its aesthetic and interaction in its operation environment. For instance, the fact that the device is expected to operate outdoors and near roads means the material must withstand Malaysia's wet weather and its movement should be able to navigate in its often uneven terrain. It must have what is necessary to operate safely in the road, ensuring traffic awareness and safe automated operation around pedestrians. Only a single device is expected to be deployed for each area, hence the product's life span must be around 5 years in order to stay economical - cheaper than manual labor.

3. CONCEPT GENERATION & SELECTION

The most pivotal step in the creation of a product is the concept generation as it requires extensive brainstorming and consideration. Firstly, the product expected functions were identified and hence a morphological chart was developed to aid in the generation of the concepts. This chart broadens the pool selections, allowing for better solutions and possibilities, and highlighting unfeasible approaches to meeting the requirements. Refer to the morphological chart in the Appendix.

3.1 Concept Generation

The three members of the engineering department charged with designing this vehicle were tasked to produce 3 concepts each; including sketches and elaborative labels as can be seen in the Appendix. The concepts were generated upon exploring different paths and variations of the best paths possible from the morphological chart. This ensured all the concepts met all the requirements. Revisions have been made in all of the concepts to ensure no external power sources are needed and more mechanical parts are implemented into the designs, as per feedback. The next step would be to thoroughly analyze the viability of each concept to *screen* for ones to be adopted as candidates for further development.

3.2 Concept Screening

In this process, all obtained concepts are put under the microscope. Influenced by the needs statement and PDS, screening criteria are put in place to govern the judging of each aspect of the concept. The vehicle's ease of use, maintenance, manufacturing and recycling; in addition to its theoretical durability and ability to operate reliably throughout its lifespan. Furthermore, a datum concept is agreed upon to set the baseline or benchmark to decide whether a concept is better (+), worse (-) or the same in a certain screening category. Each member is given another member's concepts to rate to maintain an unbiased analysis. The sum of all points for each concept is then compared and the outstanding ratings were chosen for the scoring process to determine the best concept to adopt as the main. Concepts that have adopted the chemical solution to dissolve and unclog drain blockages were given reduced scores as it was found to be less environmentally safe or friendly, causes faster wear and erosion of parts and may not be suitable for all situations. Concepts C and F were found to have the highest results, both scoring 4 out of 6 categories. Both concepts were not seen to have any superiority in terms of reliability compared to the datum concept E (Reference), however, one has proven better in ease of recycling and the other in expected durability, respectively.

3.3 Concept Scoring

Following the determination of the two most prominently leading concepts according to the set criteria, the next process aims to finalize the decision to go forward to the next steps (DFMA and FMEA) with either concepts. The scoring criteria is similar to the screening criteria; except it has more factors considered and each of them is weighted in order to achieve the most accurate grade since both concepts were tied in ranking in the screening process. The higher weighting percentages were poured into the concepts' efficacy of cleaning, operation duration and ease of maintenance. Each concept was rated from 1 to 5 from worst to best in each criterion. The rating is then multiplied by the category weightage and the sum is compared. The result of this process was due to the slight lead of concept C over F in the ease of maintenance, recycling and most importantly cleaning efficacy - scoring totals of 3.46 and 3.18 respectively.

3.4 Final Concept / Differences from initial design discussion

Ultimately, the final concept was chosen to be concept C; featuring high water pressure hose to purge its way through clogged drains and rotating brooms inspired by the pre-existing ones found in cleaning trucks to remove litter from the drains and surrounding areas that might eventually make their way there.

It can certainly be noticed, the improvement of the final concept from the initial concepts - which could have appeared promising but have failed to stay viable when analyzed. Early ideations involved the use of rollers for movement. This concept was found to not be suitable for the irregular, uneven terrain in some roads (due to potholes near drains); hence the new design implements normal truck wheels that can easily overcome any unexpected obstacle during movement. In addition, early concepts suggested the use of a diesel engine to power the vehicle which shows that it did not consider the sustainability and the physical dimensions of the product; as the vehicle must be small enough to allow for unobstructed use of the road during operation and must not be more than 50 kg.

The final concept is the result of the consideration of all factors. From the outer body, 3 features can be seen: the water refill inlet, the emergency switch stop button, and the battery recharge port (the latter two having protective covers for safety). The vehicle is approximately the size of a trolley cart and is able to hold about 34 liters of water that can be shot at clogged drains to remove persistent rubbish stuck to the insides of the gauge. Moreover, the vehicle has been fitted with 2 hazard lights for better awareness of the surroundings to its location of operation and 2 headlights to aid the automated camera-based navigation system. The two rotating brooms are expected to sweep the litter from the outer drain opening, shooting a water jet stream from the hose at the front to dislodge and remove litter inside the drain. The entire system is automated and monitored via MQTT messaging technology.

4. DFMA (Design for Manufacturing and Assembly)

A major methodology applied in product development is Design for Manufacturing and Assembly (DFMA) which reduces manufacturing costs while improving assembly. It does so by assessing the design of a product to minimize manufacturing, reduce cost and enhance quality. The purpose lies in the simplification for assembly along with reducing component count and finally manufactory enhancement to reduce cost.

DFMA finds itself indispensable in modern manufacturing for a plethora of reasons. Firstly, it facilitates cost reduction by paring down superfluous parts, curbing material wastage, and refining assembly procedures. Secondly, it elevates product quality and dependability by simplifying assembly processes and mitigating the likelihood of errors. Thirdly, it fosters scalability, enabling manufacturers to scale up production sans substantial cost escalations or complexities.

A pivotal strategy in DFMA involves slashing the number of parts within a product design while upholding or even enhancing functionality. This maneuver not only simplifies assembly but also streamlines inventory management complexities and lowers overall production costs. Through part consolidation and component standardization, manufacturers can unlock economies of scale and optimize their supply chain operations.

In this scenario, let's delve into how DFMA principles were applied to a product initially consisting of 13 discrete parts, sporting an efficiency rating of 53.8%. Through meticulous adherence to DFMA principles, the design underwent a transformative overhaul, culminating in a revised configuration featuring a mere 11 parts. This reduction in part counter heralded a substantial efficiency boost, with the revamped design boasting an efficiency rating of 63.63%.

This remarkable outcome was made possible through the implementation of several key DFMA strategies:

- Combining Support Rods with the Existing Frame: By integrating support rods into the existing frame, unnecessary components were eliminated, thereby streamlining the assembly process and enhancing design efficiency.
- Combining the Electronics Box with the Existing Body Shell: Integration of the electronics box with the body shell curtailed the need for extra components requiring specialized production. This consolidation not only simplified assembly but also optimized manufacturing processes.
- Utilizing Snap Fits and Interlocking Fasteners: The use of snap fits and other interlocking fasteners instead over the conventional bolt and nut connections reduced part count. This change also not only made improvements to assembly procedures but helped the development of design efficiency.

By embracing these DFMA strategies, the revised design not only met but surpassed the threshold for good efficiency, which typically exceeds 60%. This exemplifies the efficacy of DFMA in bolstering design efficiency and underscores its indispensability in modern product development endeavors

5. FMEA (Failure Mode Effect Analysis)

The objective of Failure Mode Effect Analysis (FMEA) is to aid engineers in identifying and classifying the possible failures of the product and the associated risks with each failure, as well as the actions needed to resolve the issue.

Hence, firstly the most likely modes of failures for this system were identified. These failure modes were considered with the entire subassemblies and functionality of the system in mind. As such, the primary systems that can be targeted by failures were listed as below:

- Tiles
- Emergency Switch
- Camera/Sensors

- ❖ Rotating Broom
- ❖ Water Hose
- ❖ Solar Panel

Once these systems are identified, reasonable conclusions must be made regarding the modes of failure for each system relative to its requirements. A failure is something that ultimately hinders its requirement to the system, disabling its ability to contribute meaningfully. Once these failures are listed, the potential effects of the failure are explored for each category. A simple rating system is used to classify the system in terms of its severity (S), the frequency of its occurrence (O) and the probability of its detection by the system (D) which follow a rating ranging from 1~10, where 10 represents the most critical parameter.

These critical parameters are further utilized in calculating a risk priority rating that defines which sub-system and functionality is at the highest risk of failure and what are the potential effects of it. Lastly, in consideration of these failures, reasonable solutions are proposed. These suggestions and reworks aim to redesign the system and remove the fatal criteria which causes the failure.

Hence, referring to the list presented above, the FMEA analysis is as tabulated below.

Item/Function	Requirements	Potential Failure Mode	Potential Effects of Failure
Tires	Movement	Air leakage or stuck	not be able to move
Emergency Switch	immediate stop	Accidental press	immediate stop when its not needed
Camera/Sensor	Navigation, Obstruction avoidance & Drain detection	Unclear or Obstructed Image, Sensor signal noise or Insufficient lighting	Unexpected, Choatic movement that is dangerous to surrounding civilians and renders the machine unusable.
Rotating Broom	Clean & Collect Litter and Junk	Brushes get bent, torn, stuck between drain cavities or clogged by excessive junk.	Scattered litter, Ineffective brooming, and distribution of junk across work area.
Water Hose	To spray water at high pressures at different angles and orientations	Pipe cracking and corrosion	Leakage of water, reduced water pressure, cleaning efficiency is reduced
		Rain corrosion	Electric battery out

Table 2. FMEA Results

As the pivotal function is regarding its mobility and efficacy in operation, the failure of its movement would hinder all functions. Considering tires are used, the likely failure mode would be due to an air leakage or other forms of puncture resulting in an inability to move. This is followed by the emergency switch, where the likely mode of failure is an accidental press, causing an immediate stop. This may be the outcome of untrained workers handling the machinery. Followed by the failure of the camera which causes immediate dysfunction of the navigation system.

The likely cause of failure is due to obstructions or deteriorations of sensors. Additionally, the next system subject to failure are the rotating brooms, the likely failure mode being the damage overtime of brooms that cause cleaning to be ineffective. Furthermore, the high pressure water dispensing relies heavily on its hose, if the hose is damaged due to cracking the likely impact is that roadside drains would not be cleared effectively. Lastly, the solar panel that provides sustainable energy to the system could fail due to rain corrosion or surface panel damage.

Once each system and its likely mode of failures are tabulated, as mentioned previously, the (SOD) ratings are determined as shown below.

Item/Function	Requirements	Potential Failure Mode	Potential Effects of Failure	Severity	Classification	Potential Causes of Failure	Current Prevention	Occurence	Problem Detection	Detection
Tires	Movement	Air leakage or stuck	not be able to move	3	A	sharp object or uneven road	flexibility and prevent air leakage	8	None	10
Emergency Switch	immediate stop	Accidental press	immediate stop when its not needed	1	A	Untrained workers handling equipment	case or lock so only authorised people can use it	10	no	10
Camera/Sensor	Navigation, Obstruction avoidance & Drain detection	Unclear or Obstructed Image, Sensor signal noise or Insufficient lighting	Unexpected, Choatic movement that is dangerous to surrounding civilians and renders the machine unusable.	5	B	Obstructed camera due to bird droppings, damaged or unclean lense, night time operation. Oblivous Pedestrian obstructing sensors, deteriorating sensor wiring or uncalibrated sensor.	Install operation lights beside camera. Include camera lense cleaner. Stop operation if inappropriate camera images or sensor readings are detected.	6	Processor recognizes unprocessable camera images and stops operation. Consecutive irregular sensor readings detection	5
Rotating Broom	Clean & Collect Litter and Junk	Brushes get bent, torn, stuck between drain cavities or clogged by excessive junk.	Scattered litter, Ineffective brooming, and distribution of junk across work area.	4	B	Weak brushes material/design, insufficient rotation speed, incorrect process execution, incorrect rotation direction or damaged brushes.	Ensure proper broom rotation speed and correct utilization.	5	Motor rotation direction detection.	8

Table 3: FMEA Severity, Occurrence and Detection

Following the simple equation below, the Risk Priority Number (RPN) is calculated to determine the most critical category of failure.

$$RPN = S * O * D$$

Item/Function	Requirements	Potential Failure Mode	Potential Effects of Failure	Severity	Classification	Potential Causes of Failure	Current Prevention	Occurence	Problem Detection	Detection	Recommended Actions	RPN	Prepared By
Tires	Movement	Air leakage or stuck	not be able to move	3	A	sharp object or uneven road	flexibility and prevent air leakage	8	None	10	Use a belt	240	Mazen Omar
Emergency Switch	immediate stop	Accidental press	immediate stop when its not needed	1	A	Untrained workers handling equipment	case or lock so only authorised people can use it	10	no	10	A case or lock to prevent pressing	100	
Camera/Sensor	Navigation, Obstruction avoidance & Drain detection	Unclear or Obstructed image, Sensor signal noise or insufficient lighting	Unexpected, Choatic movement that is dangerous to surrounding civilians and renders the machine unusable.	5	B	Obstructed camera due to bird droppings, damaged or unclean lense, night time operation. Oblivous Pedestrian obstructing sensors, deteriorating sensor wiring or uncalibrated sensor.	Install operation lights beside camera. Include camera lense cleaner. Stop operation if inappropriate camera images or sensor readings are detected.	6	Processor recognizes unprocessable camera images and stops operation. Consecutive irregular sensor readings detection	5	Ensure properly protected and shaded camera lense. Invest in sensor auto calibration and error detection software. Use high quality sensors to ensure reliability.	150	Ahmed MohamedAli
Rotating Broom	Clean & Collect Litter and Junk	Brushes get bent, torn, stuck between drain cavities or clogged by excessive junk.	Scattered litter, ineffective brooming, and distribution of junk across work area.	4	B	Weak brushes material/design, insufficient rotation speed, incorrect process execution, incorrect rotation direction or damaged brushes.	Ensure proper broom rotation speed and correct utilization.	5	Motor rotation direction detection.	8	Ensure high quality and stiff broom brushes material and effective design. Detect proper and inproper cases for broom use via image machine learning.	160	
Water Hose	To spray water at high pressures at different angles and orientations	Pipe cracking and corrosion	Leakage of water, reduced water pressure, cleaning efficiency is reduced	3	A	High water pressure causes fatigue failure of hose material. Or improper use can introduce cracks into material causing early failure and yielding.	Limit water pressure to allowable thresholds	8	Water pressure used can be detected and compared to safe values	5	Utilize more suitable material for water hose, or prevent improper use of water hose through erratic settings of water pressure by utilizing a corrective feedback mechanism that contains override for emergencies	120	Muhammad Arslan
Solar Panel	To charge up solar Battery	Rain corrosion, Deterioration due to surface damage	Electric battery out of charge/ machine is out of power	4	B	Damaged panel surface due to falling objects, rain or vandalism	None	5	Battery stops charging due to solar power	4	Utilize a foldable cover screen, a hinge locked cover or an automated slide-on plastic sheet to ensure safety and cleanliness of solar panel	80	

Table 4: Final FMEA RPN Calculations

It is determined that as speculated, the movement functionality failure is the most critical one for the system, indicated by the color scaling applied to the RPN output. This is logically verified, as if the system cannot move, there are no possibilities of it cleaning the roadside, the movement is integral to its function. The next critical function is held by the rotating brooms, followed closely by the camera system, as either of those failing would render the system unable to follow its right course, and unable to perform its required task. Lastly, the failure of the water hose, emergency switch and solar panels are not that critical, primarily due to the low severity and detection ratings as compared to others. Furthermore, the solar panels are not critical as compared to other functions, as a substitute method of charging, by directly plugging into the battery socket is available for emergencies where extra power is needed.

As discussed, each failure mode is accompanied with a modification to negate it. As tabulated in table 4, the best way to prevent tire failure is to use a multi-terrain belt that allows smooth movement in any terrain. This recommendation stems from the fact that belt driven machinery is less susceptible to punctures and can traverse more complex terrains easily. Followed by emergency switch accidental pressing, the solution is to provide a case or covering that prevents this touch, as it is not a major or critical failure it is easily resolved. Additionally, concerning rotating brooms, the recommendation mentioned is highly dependent on its application. As utilizing high quality brooms ensures that each set lasts longer but also introduces more cost to the system, the other effective technique is to utilize the brooms in the best way possible through machine learning, however this recommendation is not practical as it would require a tedious amount of data to be processed and assessed to exert a reasonable positive effect.

Moreover, in regards to the water hose failure, the recommended actions are to optimize the material selected, as well as the water pressure utilized to ensure that the safety limit is not crossed. Lastly, solar panel failure can easily be addressed by using a foldable cover type on the panel or a slide-on hook sheet that covers the panel in case of rough conditions, this prevents the panel from being damaged in the long-term, and ensures it would last for more cycles of use.

In conclusion, the FMEA (failure mode effect analysis) determines that the system's most critical junction is its mobility and it is reasonably addressed by substituting the mechanism used to one that is more durable. Each subsequent failure is effectively addressed and its risk priority number is calculated as discussed and tabulated in table 4.

6. COST ANALYSIS

The cost analysis of our product components reveals a comprehensive breakdown of expenses incurred in its manufacturing. Utilizing the Lucas method, we've meticulously evaluated the costs, considering various factors such as material availability, manufacturing methods, and external economic conditions.

From the main skeletal frame or structure, fabricated in-house using a welding process and having a cost value of 4230RM This figure includes the costs of all labor, materials and equipment used in the welding process. Although in-house manufacturing provides authority over the dimensions and quality of their product, costing should nevertheless become a top priority due to pricing.

Going to the lithium -ion batteries, imported from an online consumer market over a total cost of 2400RM. These batteries, essential for powering our product, were sourced externally to capitalize on economies of scale and benefit from competitive pricing available in the consumer market.

For the 36-liter water tank, injection molded using standardized methods, the cost stands at 300RM. Injection molding offers efficiency in producing large quantities of standardized components, contributing to cost-effectiveness in manufacturing.

Similarly, the extruded water tubing, totaling 330RM, leverages a simple and cost-efficient production method suitable for manufacturing basic plastic components. By employing extrusion, we minimize material wastage and streamline the manufacturing process, optimizing costs.

The water pump (500RM), wheels (600RM) and electric motor(400RM) components that are bought outside reveal the sourcing decisions made in strategy of balancing quality with cost cutting. By sourcing these parts from other entities, we are able to access existing supply chains and enjoy low pricing benefits offered owing to specialized manufacturers.

The wheel shafts, casted for wheel assembly, incur a cost of 2400RM. Casting enables the production of complex geometries at relatively low costs, making it a viable option for manufacturing components like wheel shafts that require precision and durability.

The high-corrosion resistance aluminum shell for the body incurs a cost of 4200 RM, reflecting the premium quality and specialized material utilized to ensure durability and performance in harsh environments.

The camera system, essential for advanced functionalities such as Lidar detection, costs 600RM. This investment in cutting-edge technology underscores our commitment to delivering innovative solutions while managing costs judiciously.

Furthermore, components like rotating brooms (700RM) and broom support rods (1200RM), manufactured using extrusion and casting methods respectively, highlight the importance of optimizing production processes to achieve cost efficiencies without compromising quality.

Lastly, the electronics box, produced using 3D printing or molding with durable plastic, incurs a cost of 350RM. This demonstrates our utilization of advanced manufacturing techniques to create lightweight yet robust enclosures for electronic components.

In sum, the total cost of all components amounts to 18210RM. Nevertheless, it must be noted that these costs are variable and changeable due to availability of materials for manufacture cited prices by manufacturers or around general economic performances. When the employed accountant's method is concerned with cost evaluation, we gain beneficial information pertaining to our cost structure that allows for an informed decision and constant perfecting of manufacturing processes.

7. RESULTS & 3D MODEL

Hence, combining all design decisions and integrating the final concept with the design specification, a rendered 3D model for each primary sub-assembly was made. This was followed by a complete assembly as shown in the figures below. Complete isometric and standard view drawings with dimensions for each sub-assembly are attached in the appendix below.

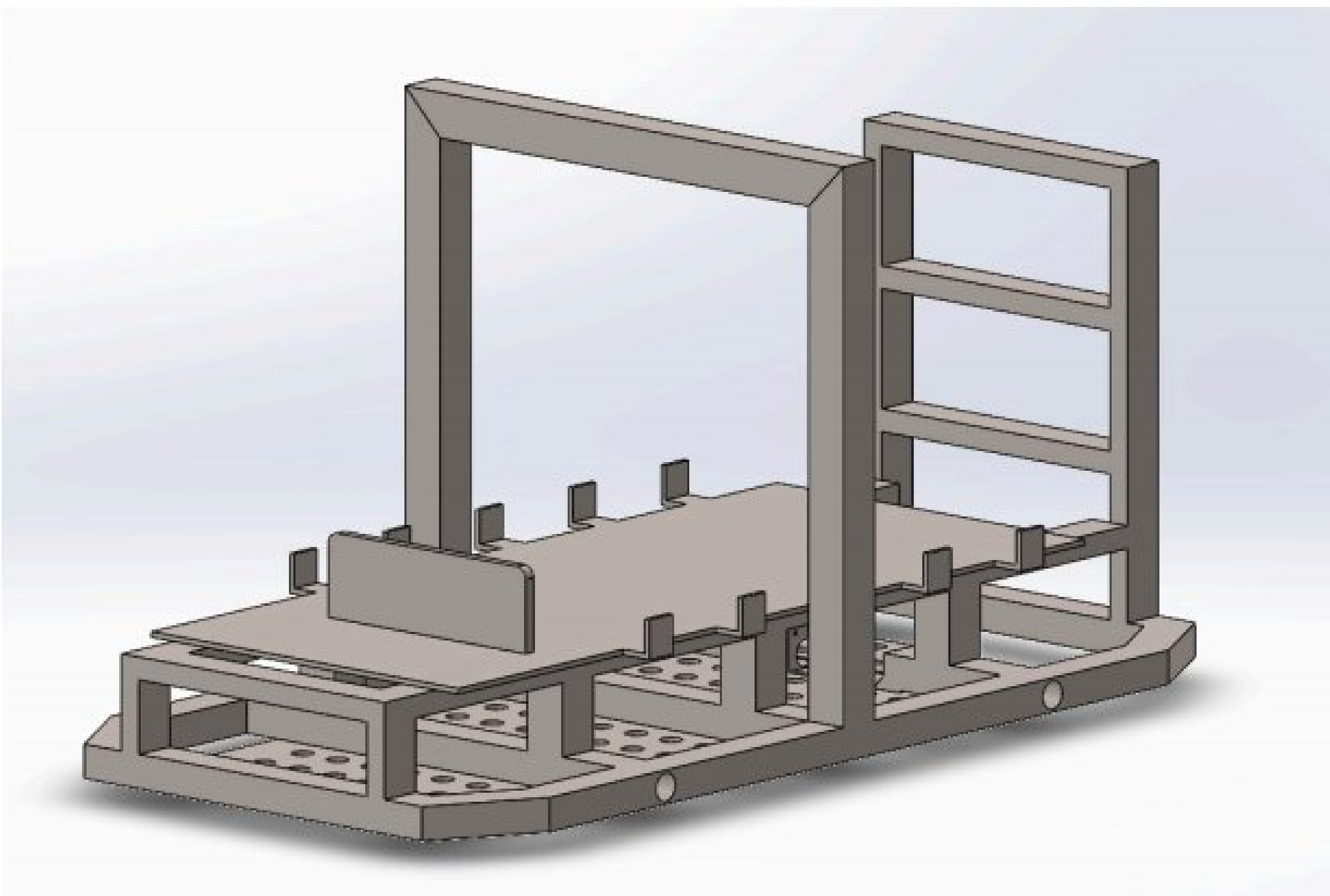


Fig 1. Frame Sub-assembly

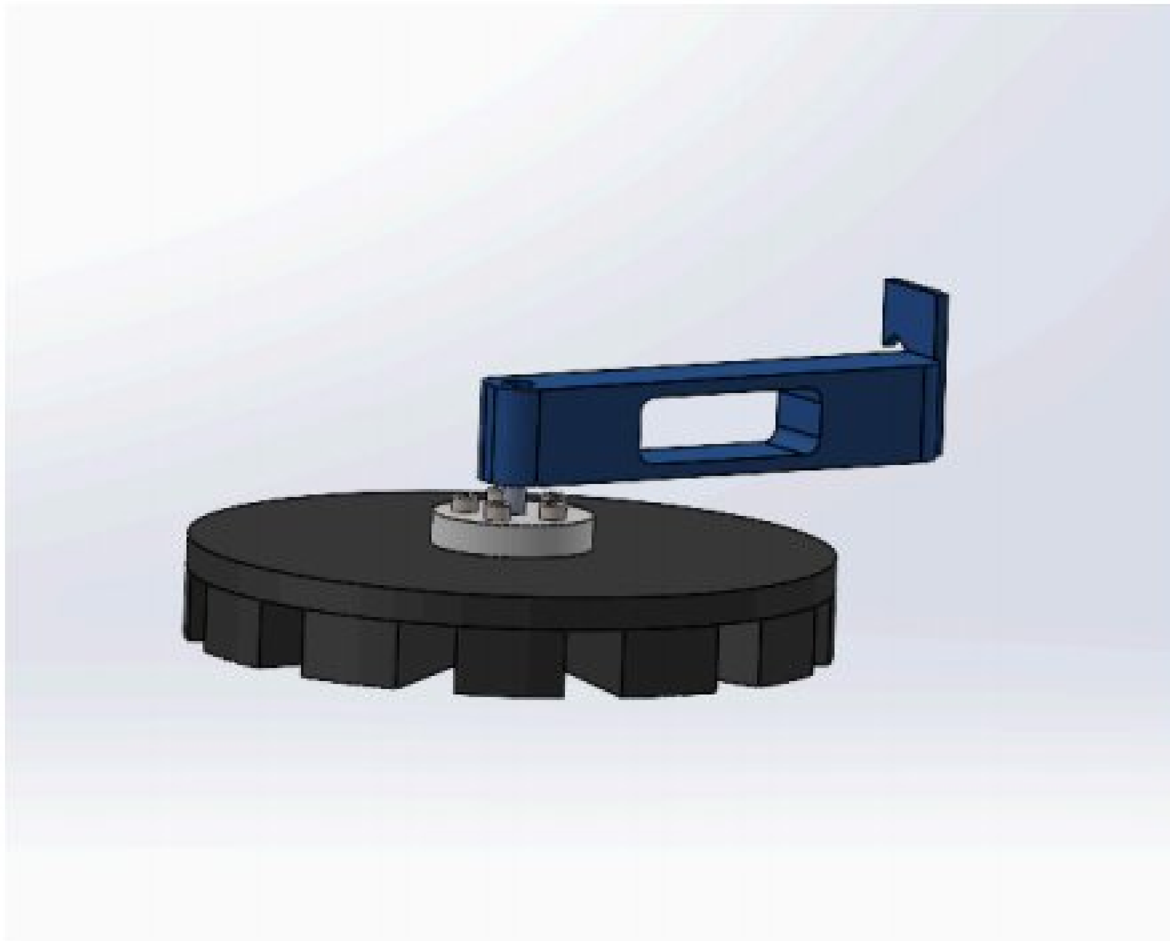


Fig 2. Rotating Brooms Sub-assembly

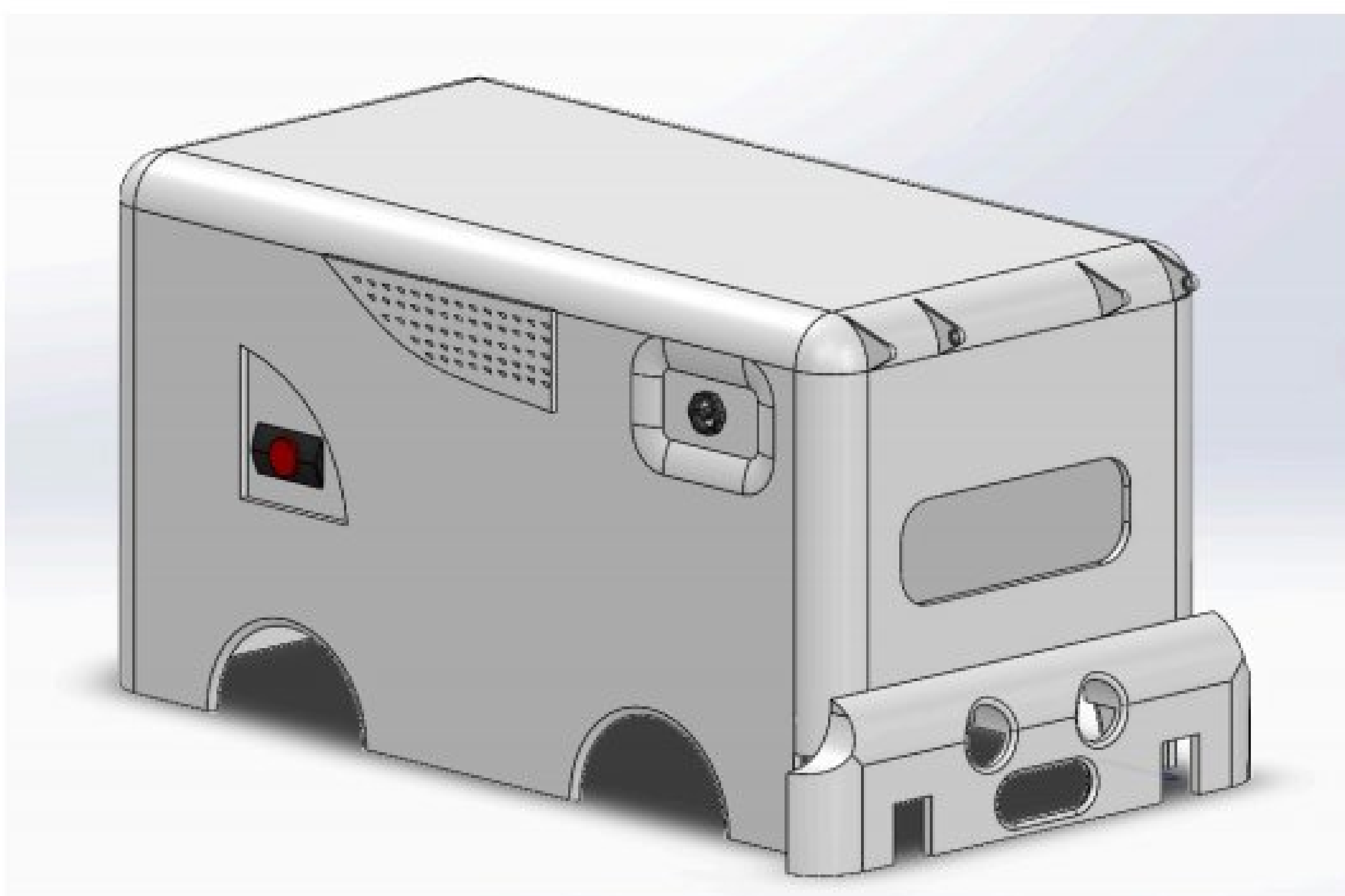


Fig 3. Body Shell

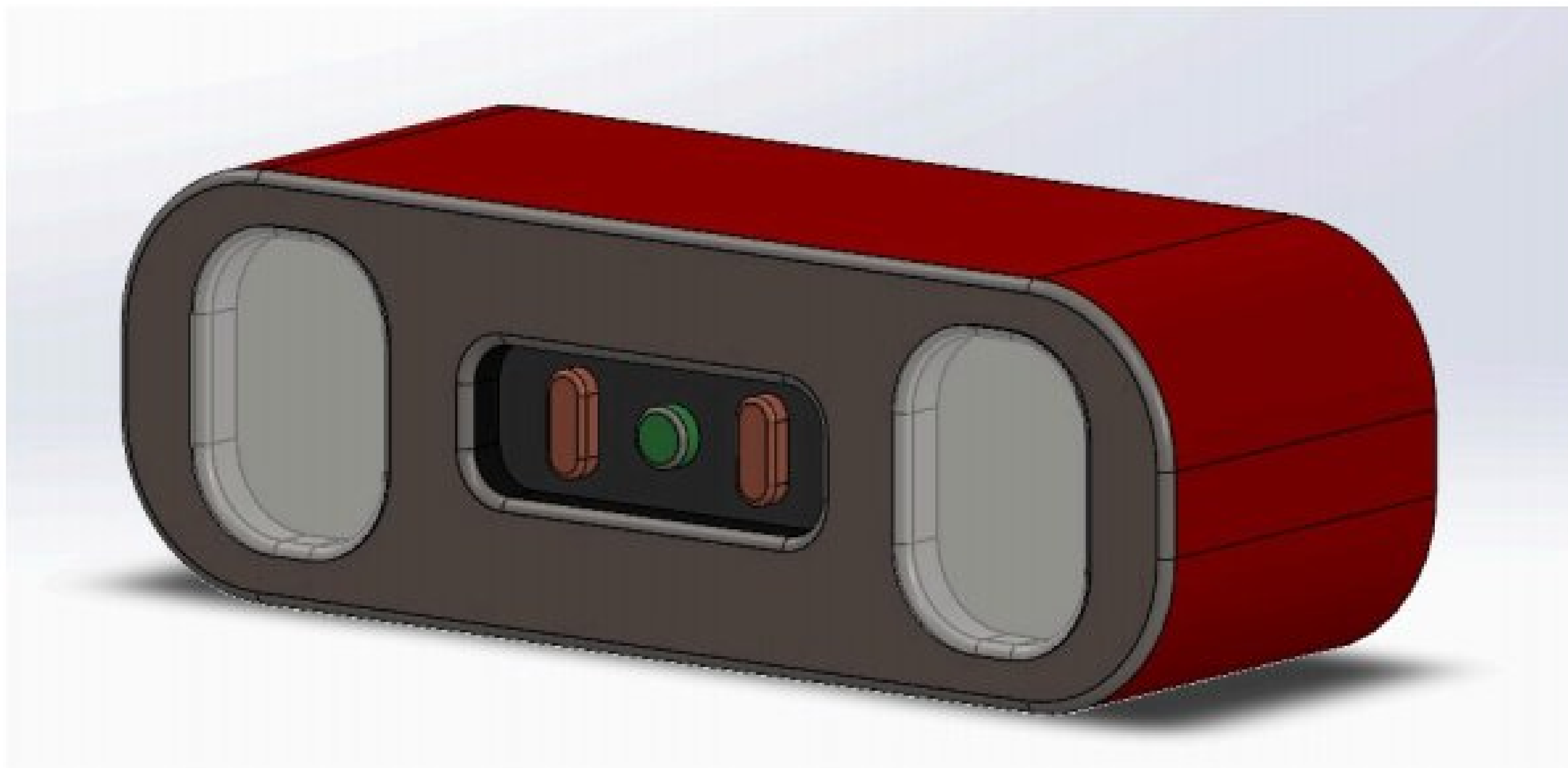
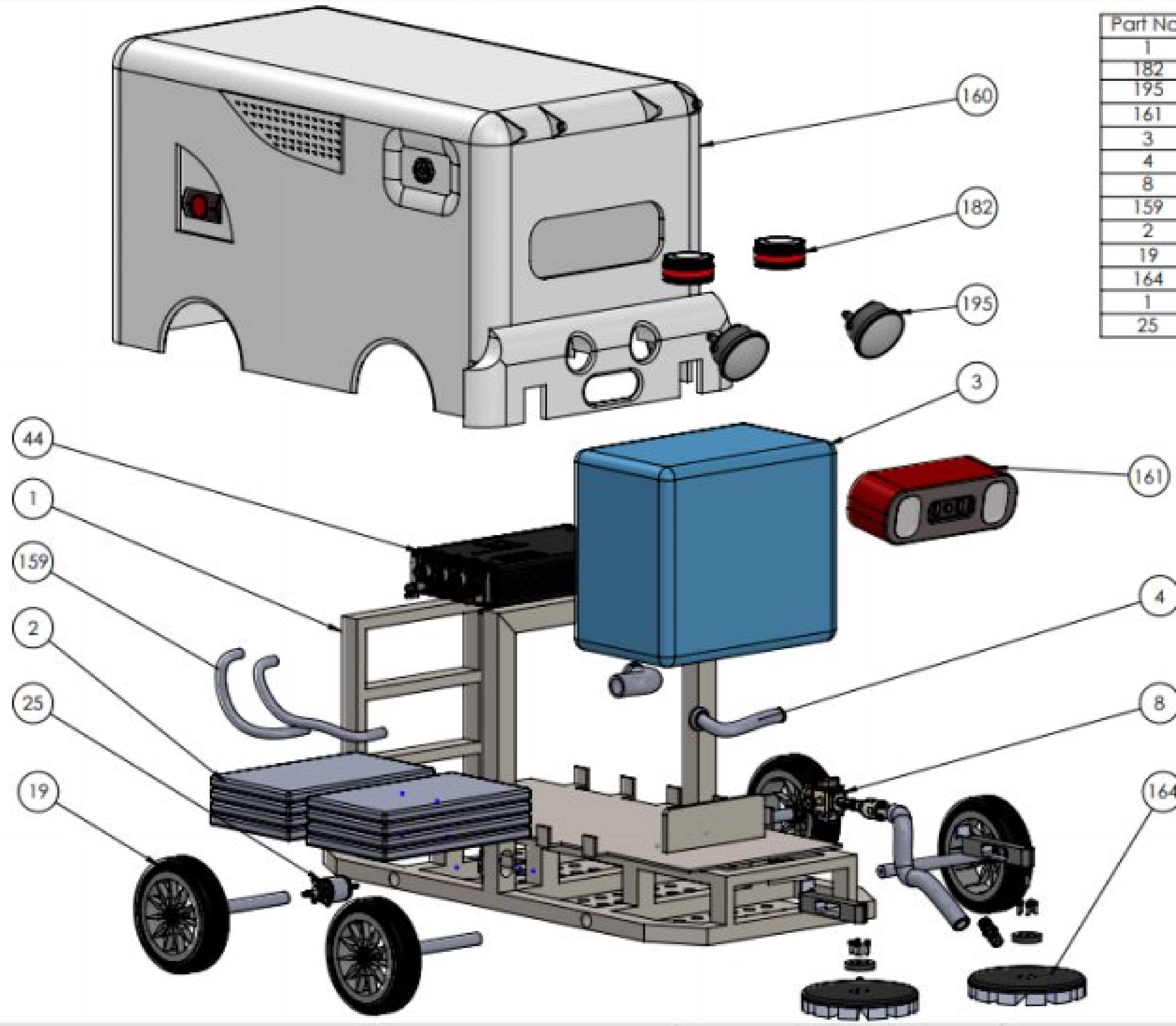


Fig 4. Camera/Sensor

Fig 5. Wheels

Hence, observing the resulting overall model and exploded view as shown in the figure below.



Part No.	Description	Quantity
1	Outer Body	1
182	Hazard Lights	2
195	Headlights	2
161	Camera + Lidar System	1
3	Water Tank	1
4	Water Tubings	2
8	Water Pump & Nozzle Assmebly	1
159	Battery Power Cables	2
2	Battery Packs	8
19	Wheel Assemblies	4
164	Broom Assemblies	2
1	Structural Frame	1
25	Electric Motor	1

Fig 6. Exploded View

The body of the machine is kitted out with every feature to mount the water tanks, electric battery and the electric motor. The body kit is lined with two emergency lights at the top to ensure visibility and overall the materials used are lightweight, and corrosion resistant as specified to combat the exposure to water. Furthermore, the body for the system is crafted as a shell, and pre-welded instead of separate panels at time of assembly, this ensures easier handling for the assemblers, as well as sustainable manufacturing as the parts do not need to be categorized and assembled like a typical car body. Overall, the resulting machine is aimed to be long lasting, easy to maintain and durable in order to boost sustainability ratings by utilizing materials and manufacturing methods that output the least carbon footprint.

8. DISCUSSION

The overall model as shown in the previous section functions perfectly in its mechanical aspects, however the system is not complete with a brief discussion on its electronic and algorithmic foundations. Firstly, the system was heavily inspired by autonomous cleaning robots, often referred to as “Roombas”, these robots are typically utilized in a house-hold setting for carpet and floor cleaning. Their main objective is to collect litter, in contrast the primary objective of the proposed system is to clear rubbish and clean drainage. However, the premise and initial concepts both align, with the idea of utilizing an autonomous robot, capable of navigation and pilot function which can effectively clean its surroundings.

Although much of the mechanical and physical design is displayed and discussed in the report, the foundation of the device is in its programming. By utilizing open-source libraries encoded in python-programming language such as OpenCV and numpy, the system can process the visual data received from the camera and sensors. This data is then used to generate a movement guideline by image processing software that highlights road lanes through a series of subsequent image transforms listed below:

1. Guassian Blur
2. Canny Edge Detection
3. Hough Line Transform

A visual demonstration of these image processing techniques can be seen in the figure below.

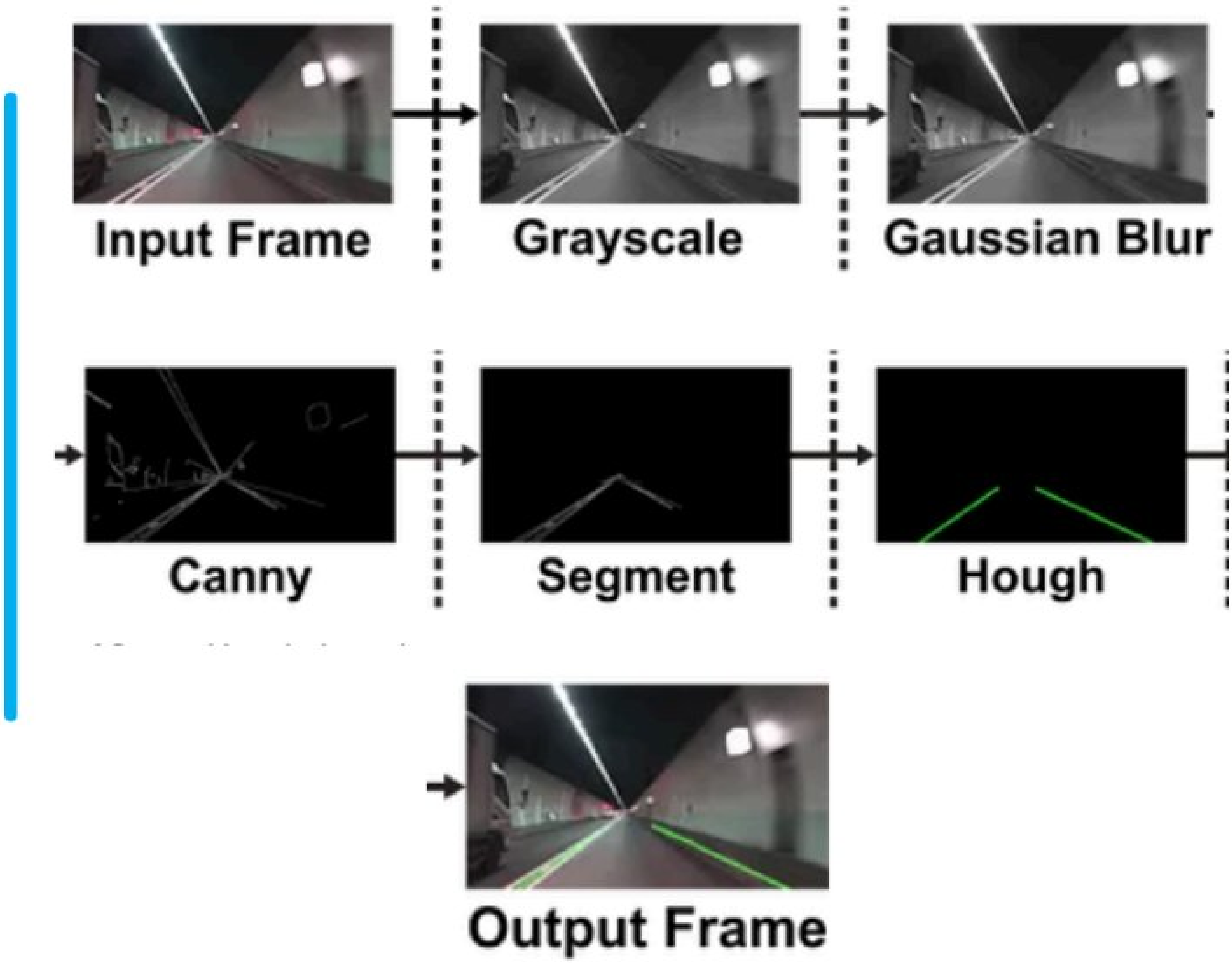


Fig 7. Image Processing procedure [2]

Hence, the camera sensor forms its own navigation guideline that an on-board processor such as a Raspberry-Pi or any other microprocessor can then use to direct its motion. This is entirely possible as the output frame shown above is not just a visual indication of the lane lines but also a mathematical model that allows the system to determine the coordinates of the lines relative to its own trajectory. As such, the system can redirect itself to remain within the lines and follow along the curb so it can function accurately.

However, the primary objective is not fulfilled as the system must be able to detect road-side drains. To fulfill this objective, a similar yet unique machine-learning model named YOLO is applied. The model excels at identifying objects by analyzing hundreds of gigabytes worth of data and forming a pattern. This machine process can allow the proposed system to recognize the look of a roadside drain through image recognition. The working principles are similar to Hough-lIne transforms, however the execution differs as the YOLO detection model recognizes recurring patterns and identifies them as objects. This detection technique is already well established and works quite well for traffic signs, as such, once the database is replaced, the recognition technique will effectively work for drains. An example of this technique can be seen below to detect street traffic signals under complex weather.

Fig 8. Example of Yolo detection [4]

As can be seen in the output frames above, the detection model can effectively recognize traffic lights in any weather condition and it works regardless of it being day or night. As such, working on the same foundational principles, it is reasonable to conclude that the same detection model can easily classify and detect blocked drains and highlight them in the systems navigation using its mathematical coordinate system, provided that its databases are organized and properly oriented with the relevant information to train its detection models.

Lastly, discussing the prototyping for this system, the biggest challenge was to integrate the idea and bring it to life as each system was far too complex to manufacture at a small scale. The image recognition software and the navigation system were too time-consuming to replicate however existing models can be found and have been shown in the figures above.

As per the mechanical construct, although it is possible to prototype, it is not feasible to construct the assembly in time according to the period available without extensive pre-planning which was difficult to integrate within the working schedule.

9. CONCLUSION

Overall, considering the initial objective and the design process, it can be noted that the proposed concept fulfills all requirements and is feasible although technologically complex to fully manufacture and utilize in the real-world. The concept focuses highly on its autonomous aspect and utilizes microprocessors, sensors and machine-learning capability to self-navigate and perform the cleaning as required by utilizing cutting-edge detection models. In conclusion, the design process was followed iteratively and refined with as much detail as possible and the resulting concept combined the best ideas and outlooks regarding an autonomous cleaner with sustainable energy, and its failures were analyzed as shown, with recommendations and suggestions on how to improve the existing design and how to simplify its assembly process.

REFERENCES

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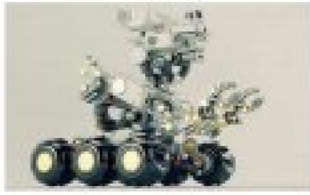
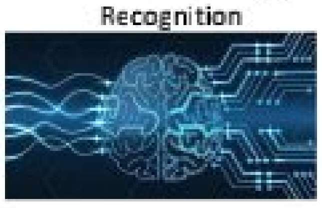
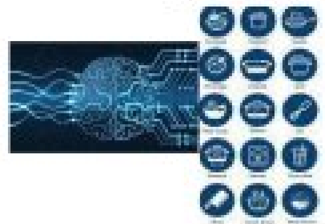
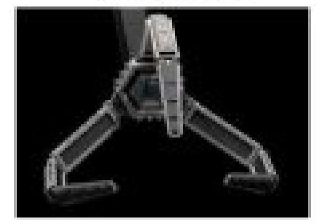
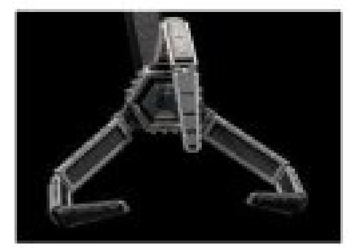
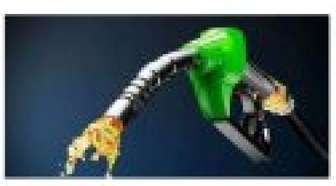
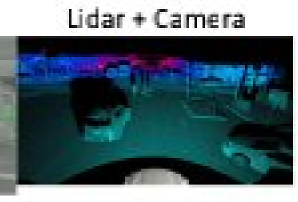
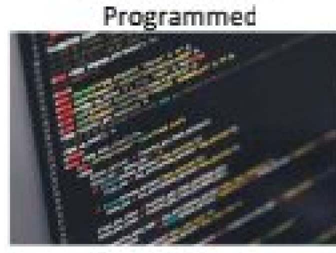
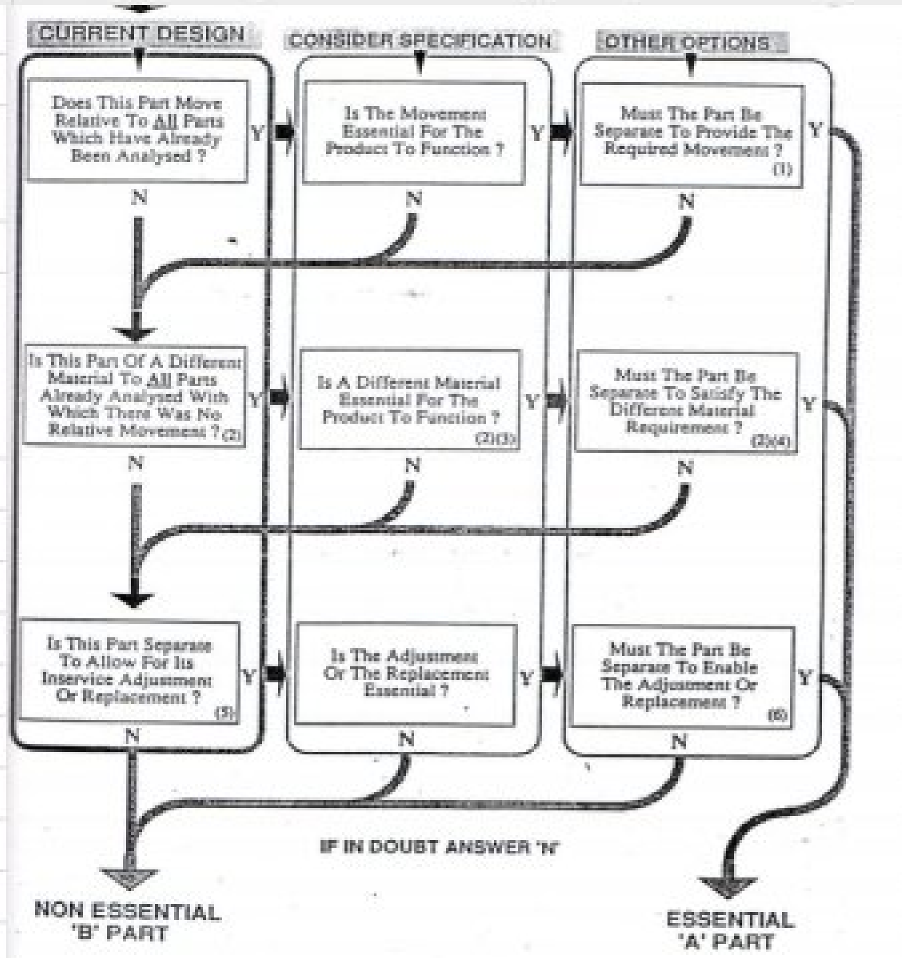
APPENDIX

Functions/Options	1	2	3	4	5
Move	Tires 	Rollers 	Belt 		
Navigate	AI Machine Learning & Recognition 	Preset programs 	AI recognition & Preset Program 		
Clear/Sweep Trash	Broom/brush 	Rake 	Vacuum 	Grabber 	Robotic Claw 
Unclog drain	High water pressure hose 	Drain Snake 	Air hose 	Chemical 	Robotic Claw 
Report issues	Sms message 	Wifi notification 	MQTT message 	LoRa notification 	
Power	Petrol 	Diesel 	Solar 	Electric Battery 	
Sensors	Lidar (Radio) 	Camera 	Infrared 	Lidar + Camera 	
Interface	Screen 	Application 	None/ Developer Programmed 	Preset Switches & LCD screen 	

DESIGN EFFICIENCY CALCULATION		
COMPONENT / PART	***COMPONENT TYPE***	***REASONING***
Skeletal Frame/ Structu	A	Frame is made of steel material that must be separated for extra durabiility
Lithium Ion Batteries	A	Batteries are made of dielectric material for best conductivity and poiwer storage
36 Litre Water Tank	B	Tank is not made of any essential material and is stationary
Water Tubing	B	Tubing is not made of essential material and is stationary
Water Pump	A	Water pump is an electronic component and cannot be combined with other parts
Wheel	A	Wheels must rotate to provide movement
Wheel shafts	A	Shaft of wheel must rotate to transmit power from electric motor
Electric Motor	A	Motor is not a component that can be combined
Body Shell	B	Body Shell can be made of same material as frame and manufactured as one complete husk
Camera System	B	Camera System/Box can be interaged into frame
Rotating Brooms	A	Rotating brooms must be flexible and able to move
Broom Support Rods	B	Support rods are rigid and can be integrated into frame
Electronics Box	B	Box is made of plastiic and can be integrated into frame and other body aspects

Design Efficiency (%)	53.84615385

TEMPLATE TO DETERMINE COMPONENT TYPE

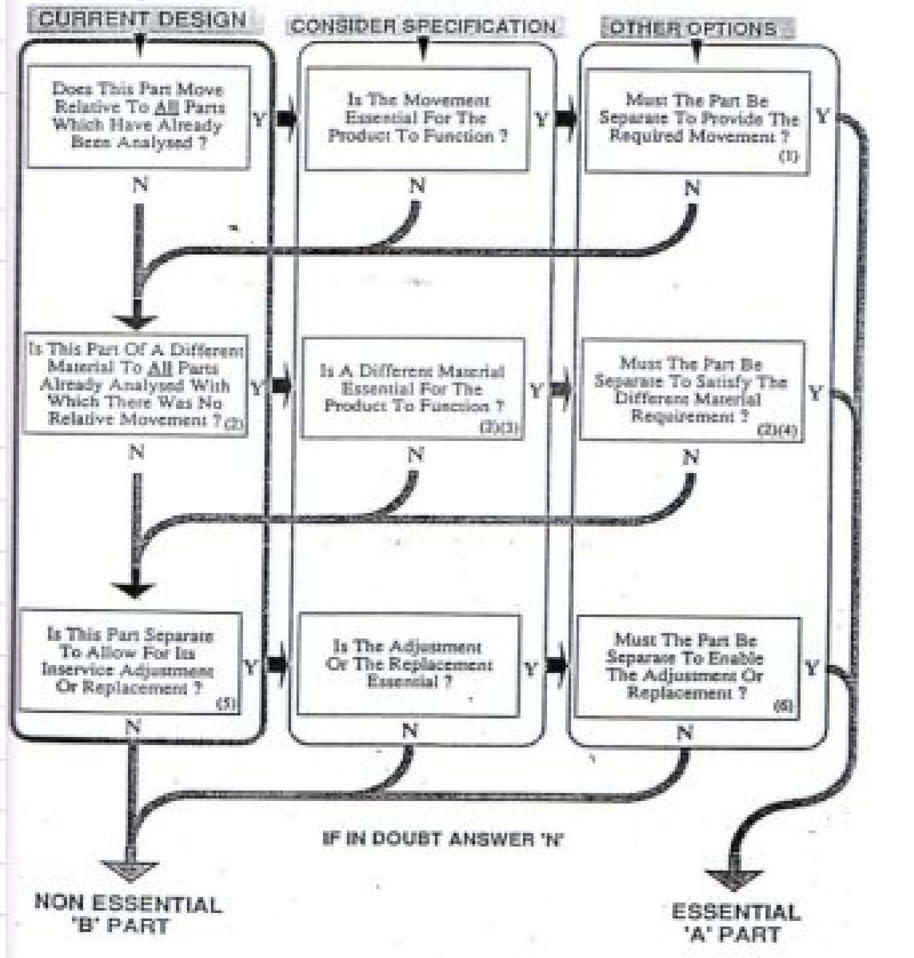


DESIGN EFFICIENCY CALCULATION

COMPONENT / PART	*COMPONENT TYPE*	*REASONING*
Skeletal Frame/ Structu	A	Frame is made of steel material that must be separated for extra durabiility
Lithium Ion Batteries	A	Batteries are made of dielectric material for best conductivity and poiwer storage
36 Litre Water Tank	B	Tank is not made of any essential material and is stationary
Water Tubing	B	Tubing is not made of essential material and is stationary
Water Pump	A	Water pump is an electronic component and cannot be combined with other parts
Wheel	A	Wheels must rotate to provide movement
Wheel shafts	A	Shaft of wheel must rotate to transmit power from electric motor
Electric Motor	A	Motor is not a component that can be combined
Body Shell	B	Body Shell can be made of same material as frame and manufactured as one complete husk
Camera System	B	Camera System/Box can be interaged into frame
Rotating Brooms	A	Rotating brooms must be flexible and able to move

Design Efficiency (%)	63.63636364

TEMPLATE TO DETERMINE COMPONENT TYPE



1. Combine the Support rods with existing frame and educe number of parts to increase design efficiency
2. Combine electronics box with Existing Body Shell to reduce number of extra componenets requiring special production
3. Use Snap Fits and other interlocking fasteners instead of bolt and nuts to reduce number of parts

Item/Function	Requirements	Potential Failure Mode	Potential Effects of Failure	Severity	Classification	Potential Causes of Failure	Current Prevention	Occurence	Problem Detection	Detection	Recommended Actions	RPN	Prepared By
Tires	Movement	Air leakage or stuck	not be able to move	3	A	sharp object or uneven road	flexibility and prevent air leakage	8	None	10	Use a belt	240	Mazen Omar
Emergency Switch	immediate stop	Accidental press	immediate stop when its not needed	1	A	unworthy people	case or lock so only authorised people can use it	10	no	10	A case or lock to prevent pressing	100	
Camera/Sensor	Navigation, Obstruction avoidance & Drain detection	Unclear or Obstructed Image, Sensor signal noise or Insufficient lighting	Unexpected, Choatic movement that is dangerous to surrounding civilians and renders the machine unusable.	5	B	Obstructed camera due to bird droppings, damaged or unclean lense, night time operation. Oblivous Pedestrian obstructing sensors, deteriorating sensor wiring or uncalibrated sensor.	Install operation lights beside camera. Include camera lense cleaner. Stop operation if inappropriate camera images or sensor readings are detected.	6	Processor recognizes unprocessable camera images and stops operation. Consecutive irregular sensor readings detection	5	Ensure properly protected and shaded camera lense. Invest in sensor auto calibration and error detection software. Use high quality sensors to ensure reliability.	150	Ahmed MohamedAli
Rotating Broom	Clean & Collect Litter and Junk	Brushes get bent, torn, stuck between drain cavities or clogged by excessive junk.	Scattered litter, Ineffective brooming, and distribution of junk across work area.	4	B	Weak brushes material/design, insufficient rotation speed, incorrect process execution, incorrect rotation direction or damaged brushes.	Ensure proper broom rotation speed and correct utilization.	5	Motor rotation direction detection.	8	Ensure high quality and stiff broom brushes material and effective design. Detect proper and inproper cases for broom use via image machine learning.	160	
Water Hose	To spray water at high pressures at different angles and orientations	Pipe cracking and corrosion	Leakage of water, reduced water pressure, cleaning efficiency is reduced	3	A	High water pressure causes fatigue failure of hose material. Or improper use can introduce cracks into material causing early failure and yielding.	Limit water pressure to allowable thresholds	8	Water pressure used can be detected and compared to safe values	5	Utilize more suitable material for water hose, or prevent improper use of water hose through erratic settings of water pressure by utilzing a corrective feedback mechanism that contains override for emergencies	120	Muhammad Arslan
Solar Panel	To charge up solar Battery	Rain corrosion, Deterioration due to surface damage	Electric battery out of charge/ machine is out of power	4	B	Damaged panel surface due to falling objects, rain or vandalism	None	5	Battery stops charging due to solar power	4	Utilize a foldable cover screen, a hinge locked cover or an automated slide-on plastic sheet to ensure safety and cleanliness of solar panel	80	

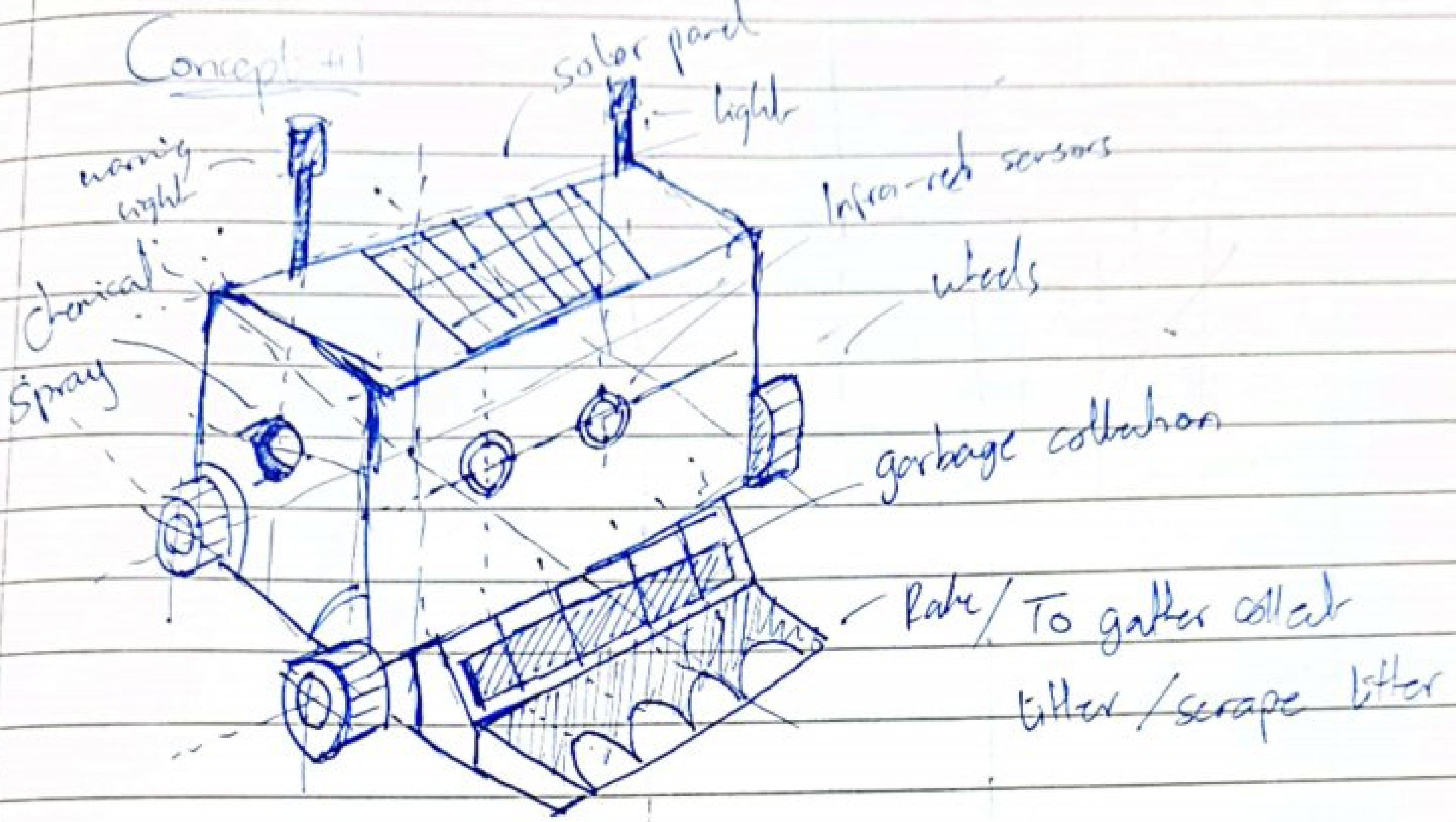
PRODUCT / PART	MANUFACTURING COST ESTIMATES (Lucas Method)							
	QTY	PROCESS / METHOD	MATERIAL	MATERIAL COST (RM)	PROCESSING (Labor) / (Unit) COST (RM)	TOOLING COST (RM)	Total COST (RM)	Reference
Skeletal Frame/ Structure	1	Welding	Steel	4000	230	0	4230	Manufactured in house with welding
Lithium Ion Batteries	8	N.A	N.A	0	300	0	2400	Purchased from online consumer market, Lithium Solar Batteries
36 Litre Water Tank	1	Injection Molding	High Density Plastic	200	100	0	300	Injection Molded for a standard water storage tank
Water Tubing	3	Extrusion	Plastic	40	70	0	330	Extruded for simple plastic tubings
Water Pump	1	N.A	N.A	500	0	0	500	Purchased externally
Wheel	4	N.A	N.A	150	0	0	600	Purchased Externally
Wheel shafts	4	Casting	Steel	300	300	0	2400	Casted for wheel assembly
Electric Motor	1	N.A	N.A	0	400	0	400	Purchased from manufacturer
Body Shell	1	Casting	Aluminium	4000	200	0	4200	High-corrosion resistance Aluminium shell casted.
Camera System	1	N.A	N.A	0	600	0	600	Camera capable of Lidar detection with High-Res input
Rotating Brooms	2	Extrusion	Fiber/Plastic	300	50	0	700	Simple extrusion process to get fiber strands for broom head that can be glued together
Broom Support Rods	2	Casting	Steel	400	200	0	1200	Casted Support Rods
Electronics Box	1	3D-Print/ Injection Molding	Plastic	200	150	0	350	3D Printed or molded using durable and lightweight plastic
					TOTAL MANUFACTURING COST (RM)		18210	

Total cost does not represent an accurate estimate to manufacture and use this product. As the navigation system is based upon machine learning software that requires skilled engineers to set up and maintain over the period of use. Hence, the cost calculated only represents the manufacturing and assembly cost for one unit produced, without any software capability

"No." and "Date" printed in top right corner, blank.

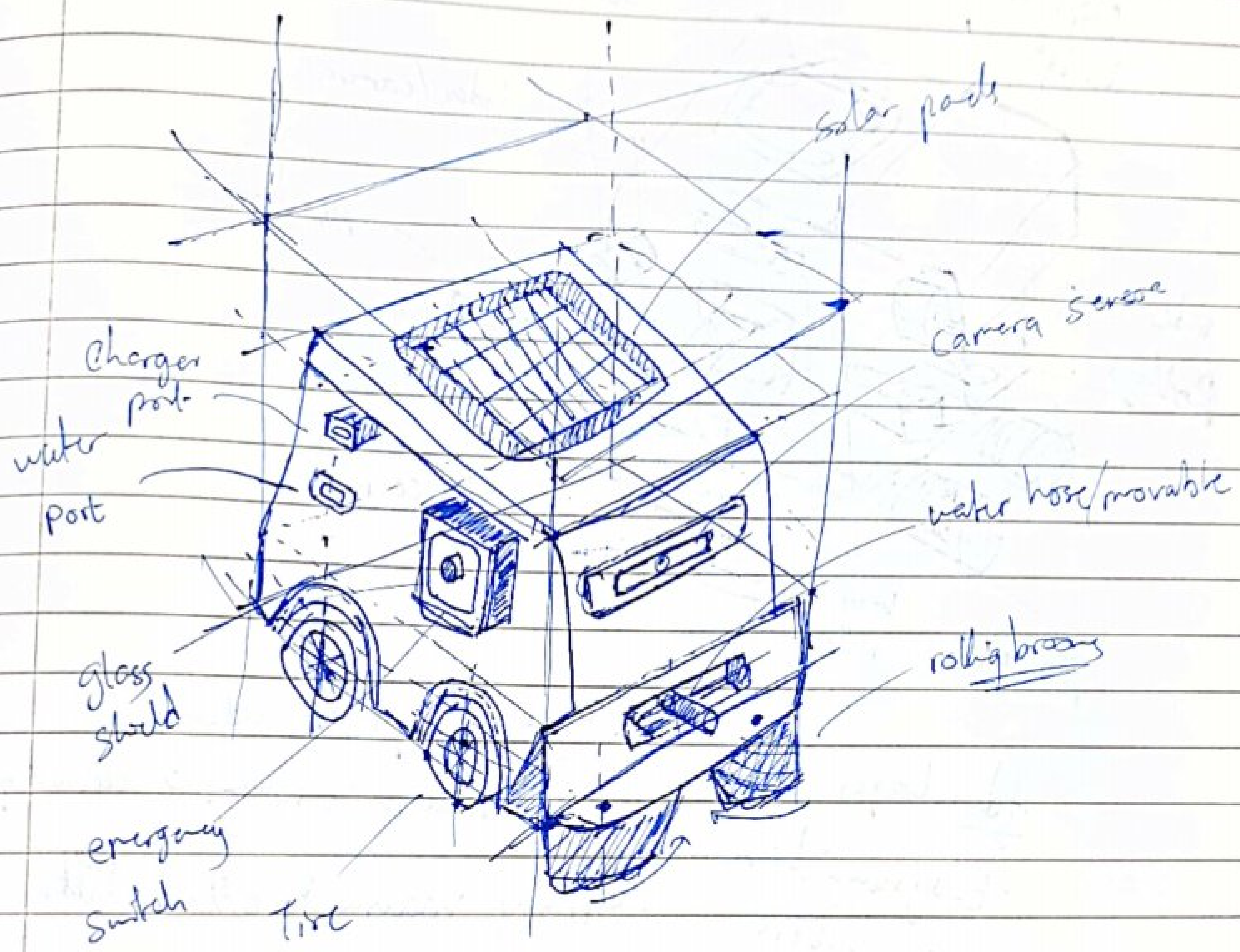
Concept sketching

Concept #1



- Regular sprays of cleaning chemicals decompose organic material stuck in drains
- Rake ~~sey~~ scrapes litter and deposits into gap for collection
- System navigates using infra-red sensors
- control module can send sms message in case of assistance.

Concept sketching

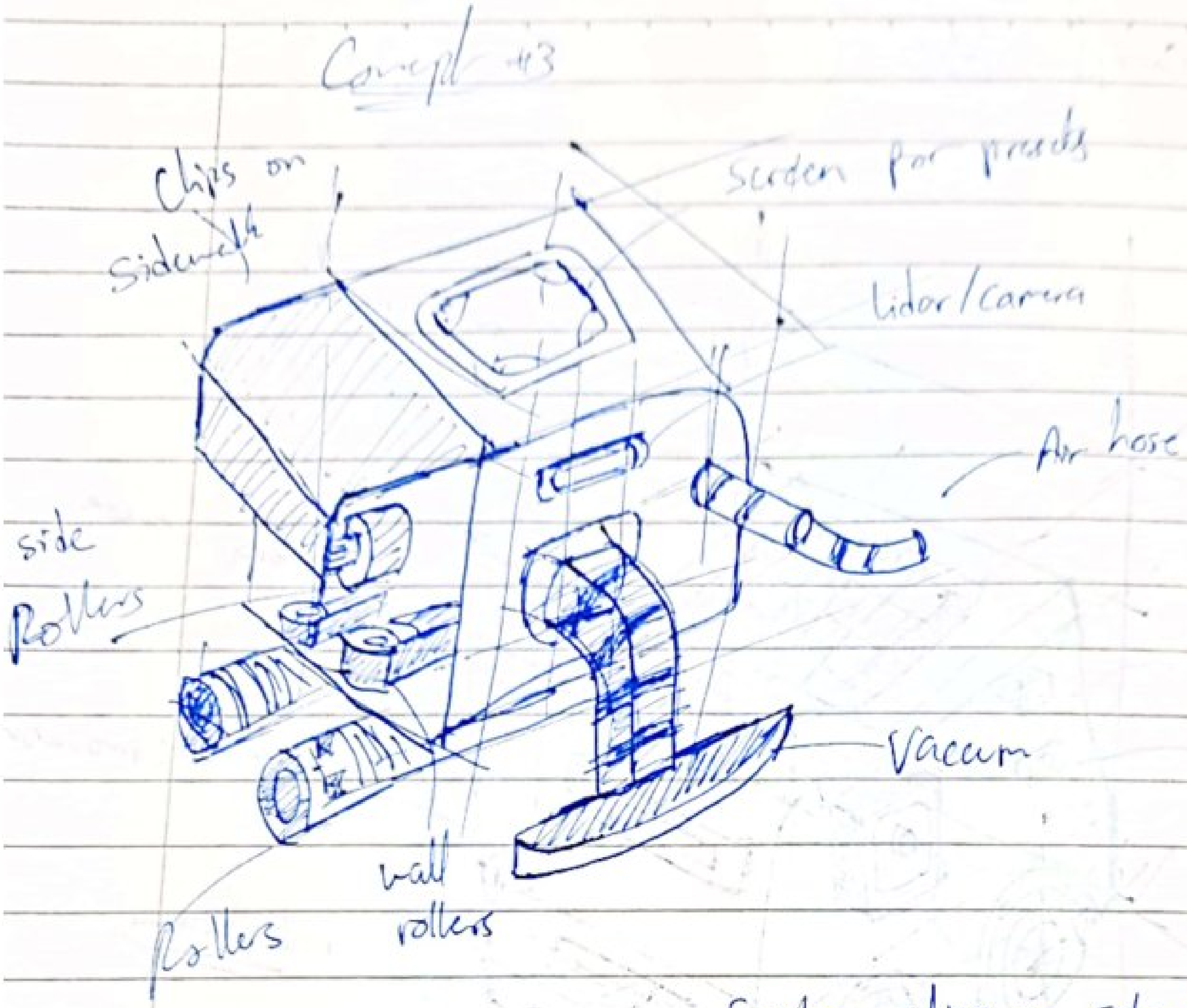


- Rollers sweep trash in to collection

- solar panel keeps device charged/ port for emergency charging

- Water hose 180° movement/ target blockage and spray to remove / fill water through port

Concept #3



Advantages

- Easy navigation using rollers

Disadvantages

- Lidar + Camera expensive
- needs programer

- System clips on sidewalk. Uses rollers to navigate accordingly
- Strong vacum to collect litter
- Air hose to blast drainage with air to unclog
- LCD screen for maintenance work and to show current preset

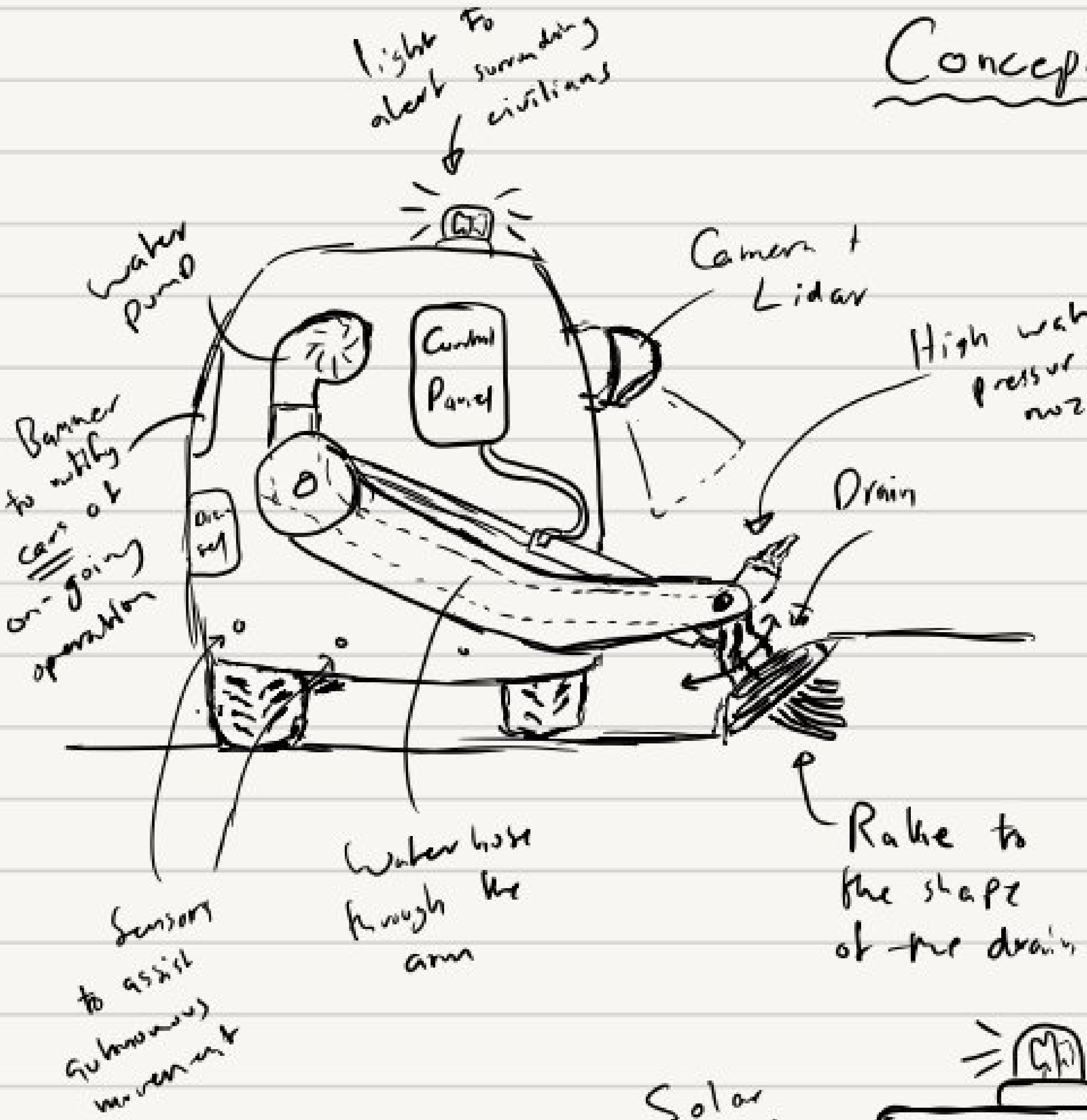
AHMED MOHAMEDALI
A20EM3002

Product Design Project
Concept Generation

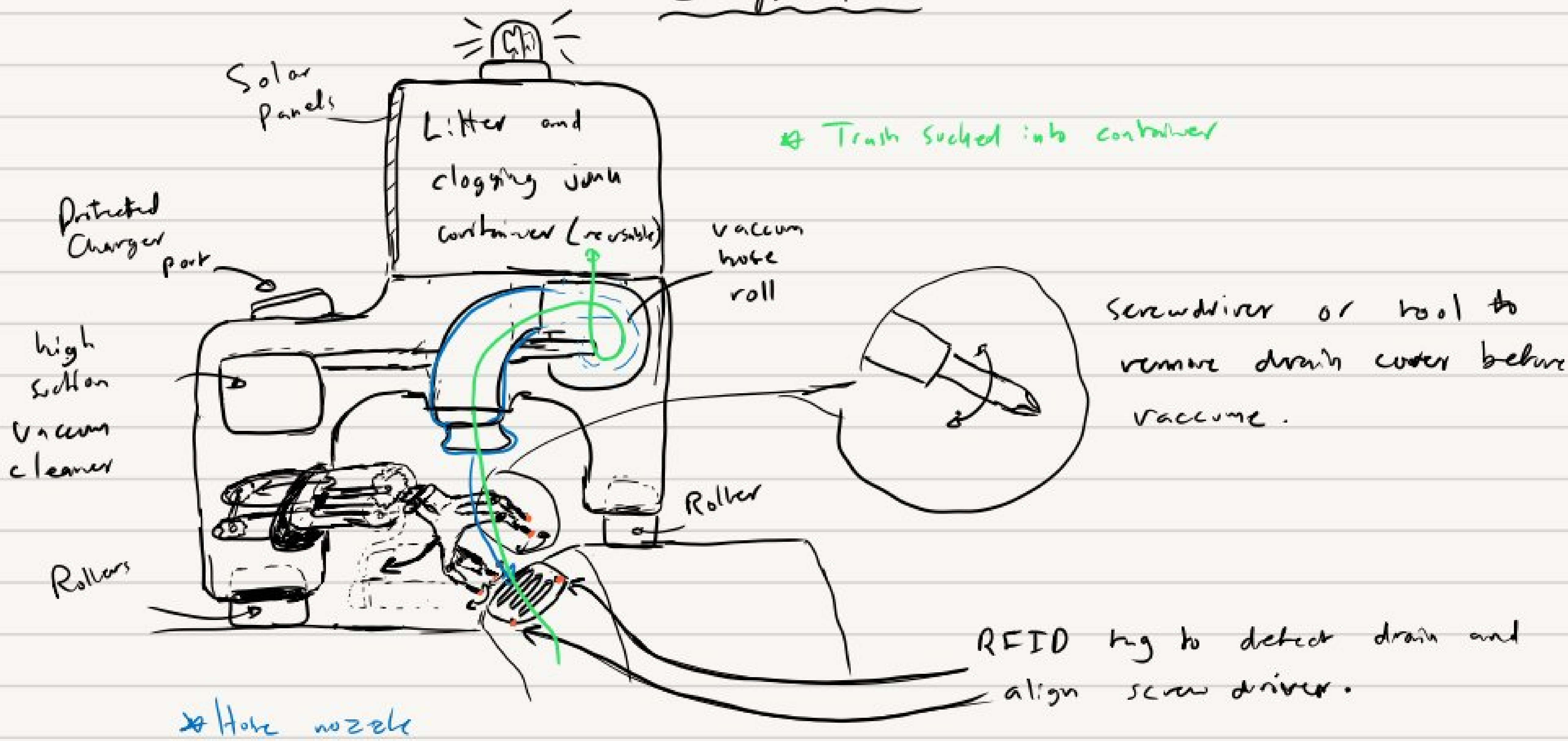
* Objectives:
  - → Follows PDS (needs statements)
  - → Cheap and easy → manufacture
    - ↳ Use
    - ↳ Maintain
    - ↳ Implement
  - → Efficient & Effective

* PDS:
  - → Autonomous
  - → Collect litter
  - → Clean "
  - → Maintaining Drain System
  - → Corrosion resistant
  - → Durable
  - → Suitable for night time operation

Concept One



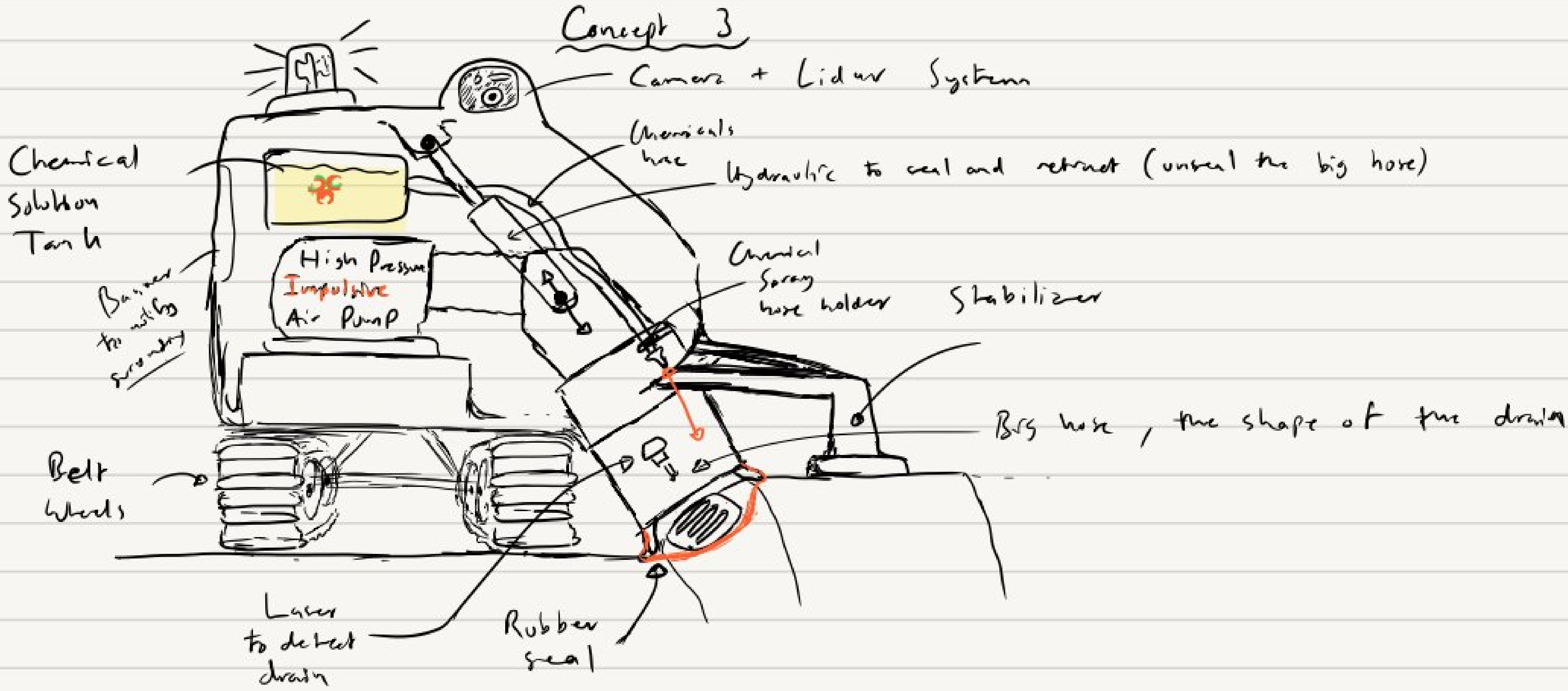
Concept Two



* Hose nozzle shape matches the drain opening shape

* This concept can be modified to have a water tank on top (instead of junk container) and a high pressure water hose instead of the vacuum cleaner.

Concept 3



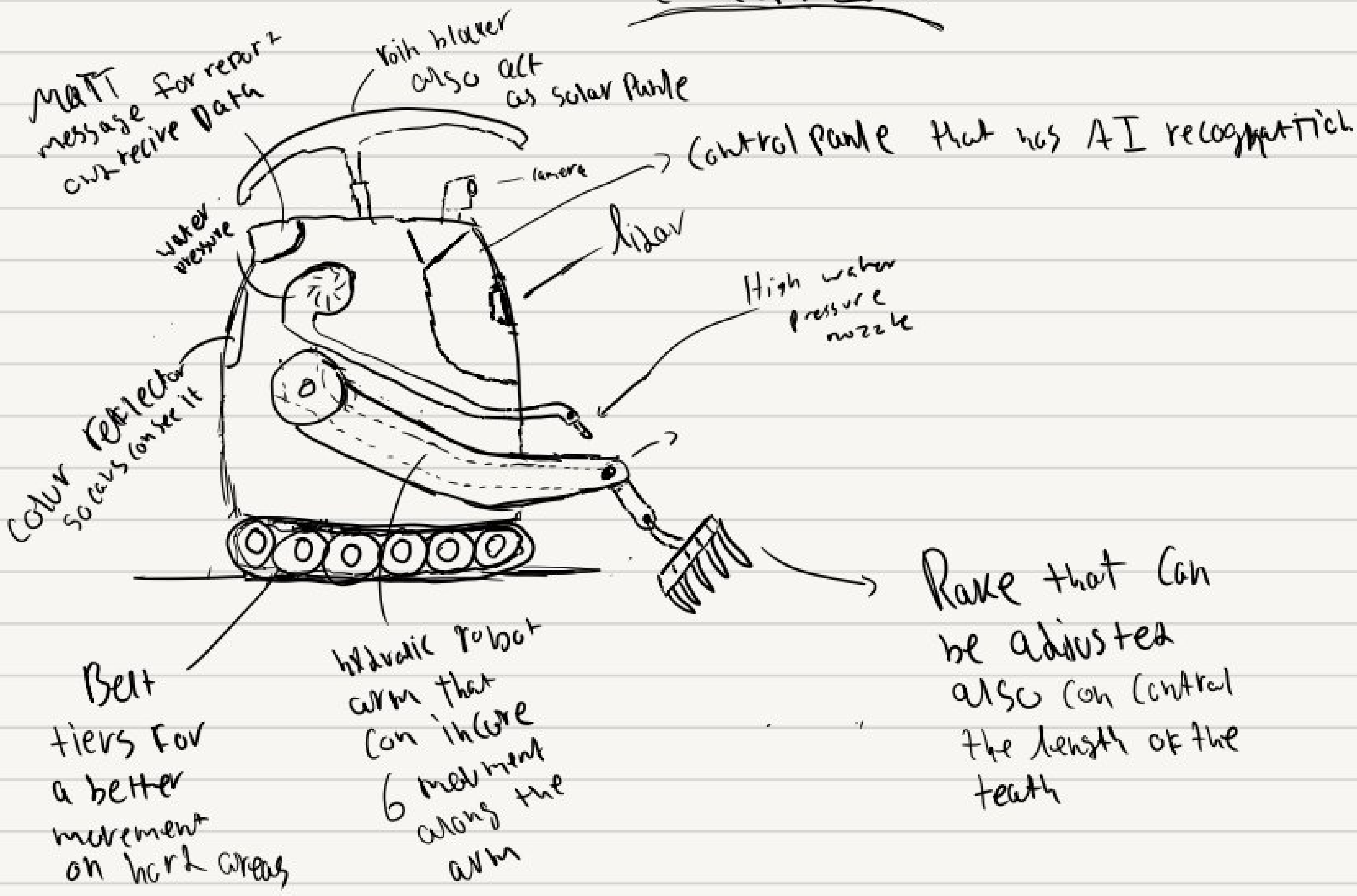
Camera + Lidar System
Chemical Solution Tank
Chemicals hose
Hydraulic to seal and retract (unseal the big hose)
High Pressure
Impulsive
Air Pump
Banner to notify surrounding
Chemical Spray hose holder
Stabilizer
Big hose, the shape of the drain
Belt Wheels
Laser to detect drain
Rubber seal

Mazen Omar
A20EM 4015

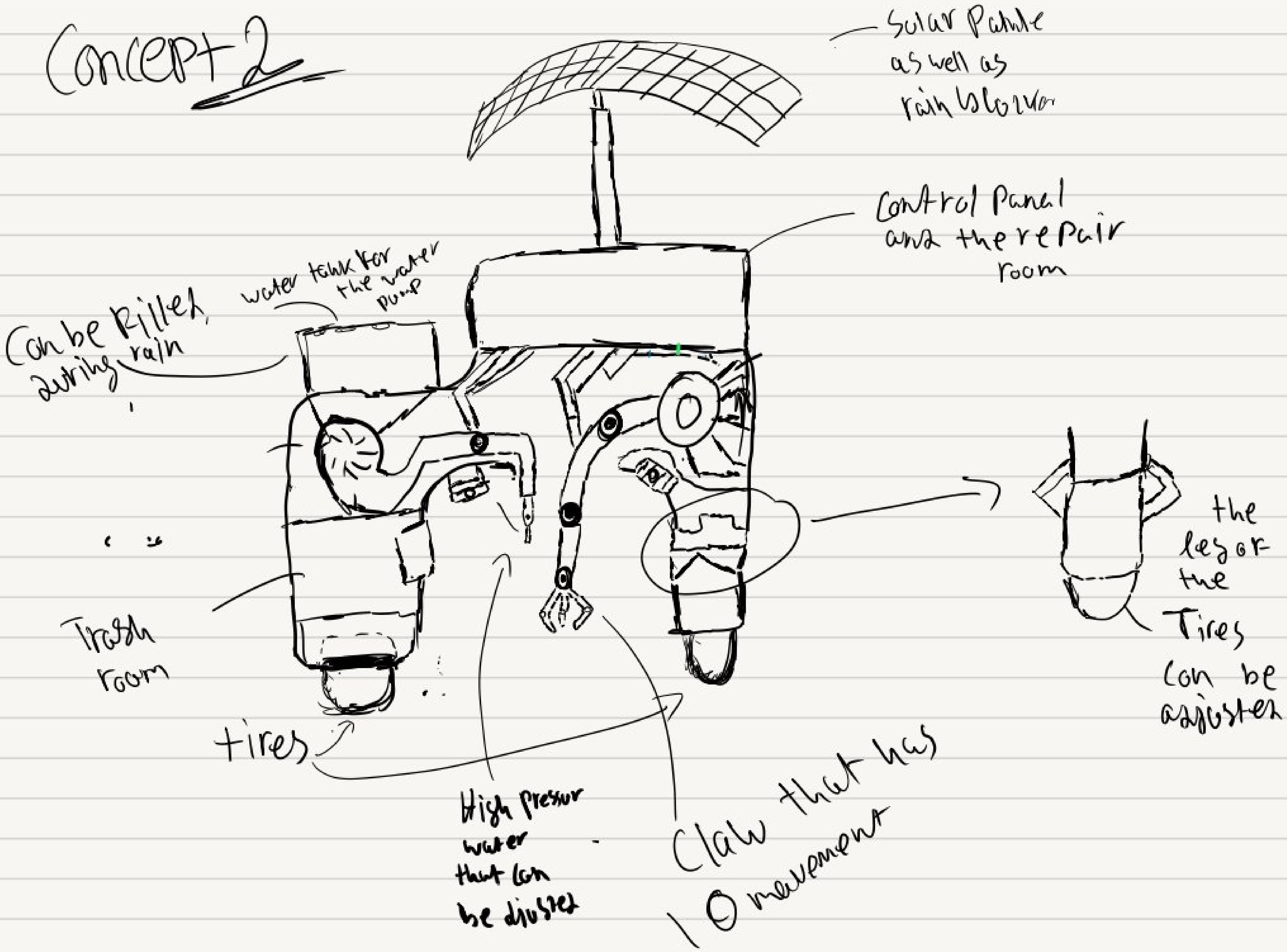
* Objectives:
  - → Follow PDS (needs statements)
  - → Cheap and easy → manufacture
    - ↳ Use
    - ↳ Maintain
    - ↳ Implement
    - ↳ replicable
    - ↳ renewable
  - → Efficient & Effective

* PDS:
  - → Autonomous
  - → Collect litter
  - → Clean litter
  - → maintain Drain system
  - → Corrosion resistant
  - → Durable
  - → Suitable for night time

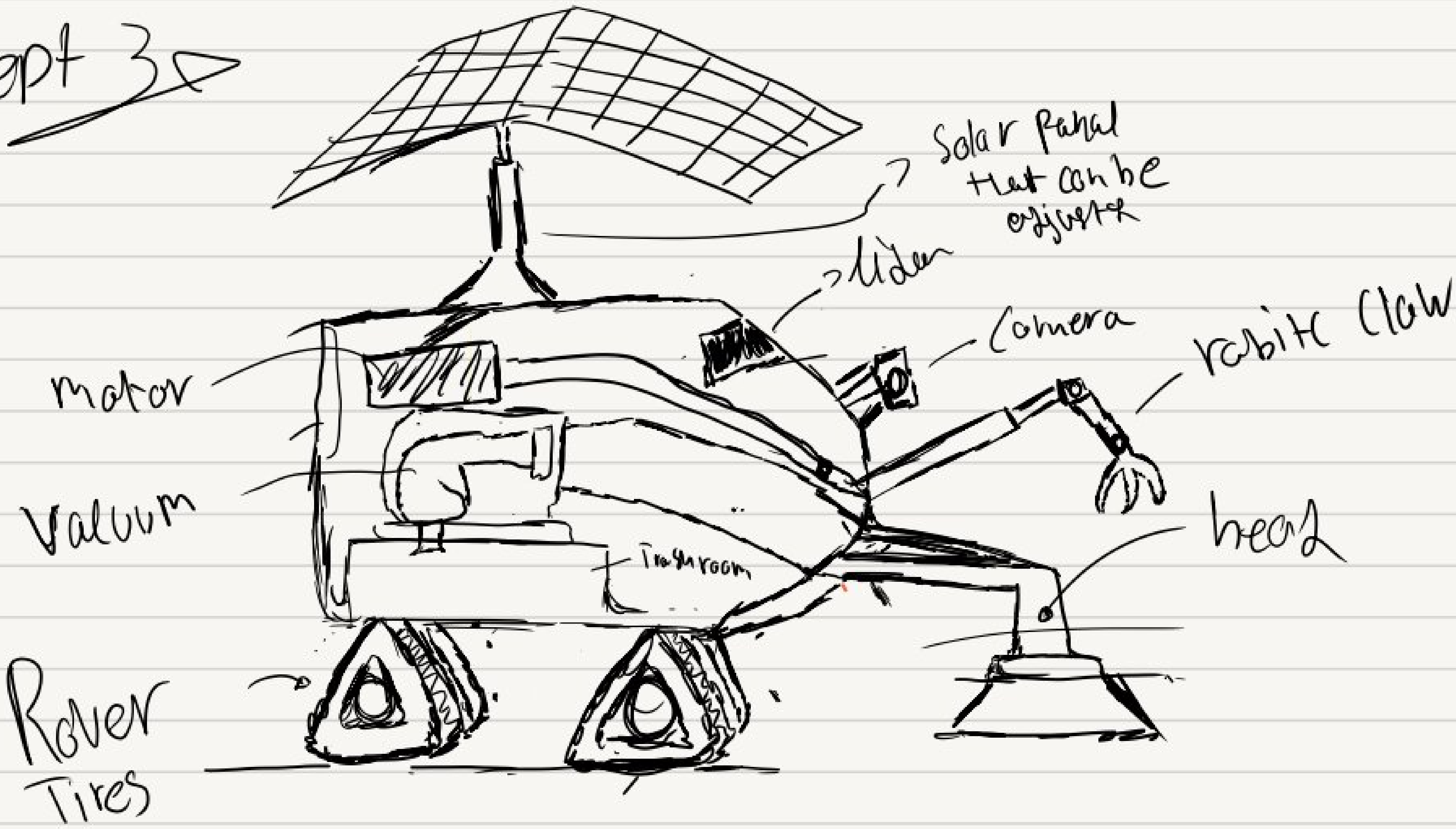
Concept 1



Concept 2

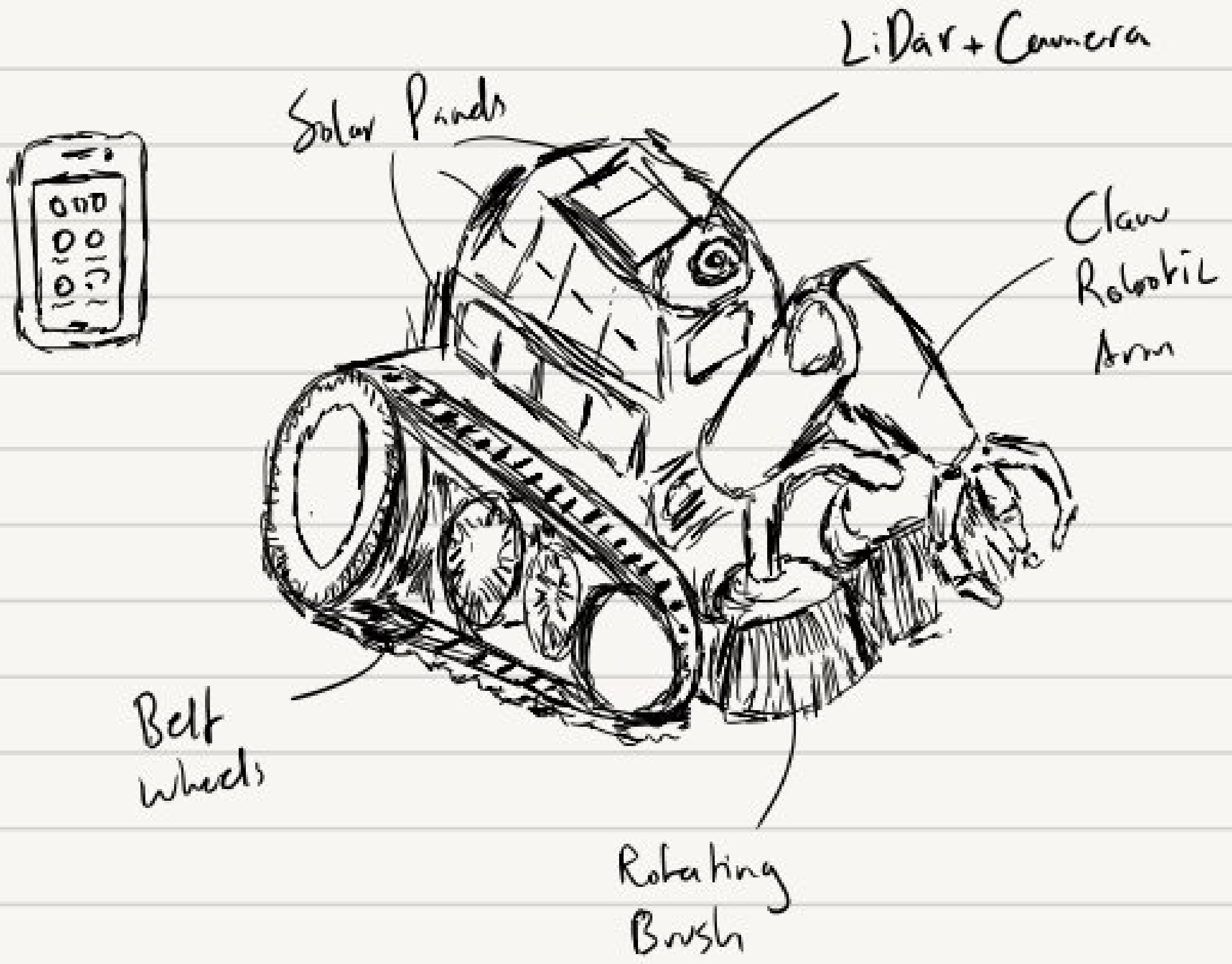

Solar Panle as well as rain blozwer
Control Panel and the repair room
water tank for the water pump
Can be filled during rain
Trash room
tires
High presur water that can be djusted
Claw that has 10 movement
the legs of the Tires can be adjusted

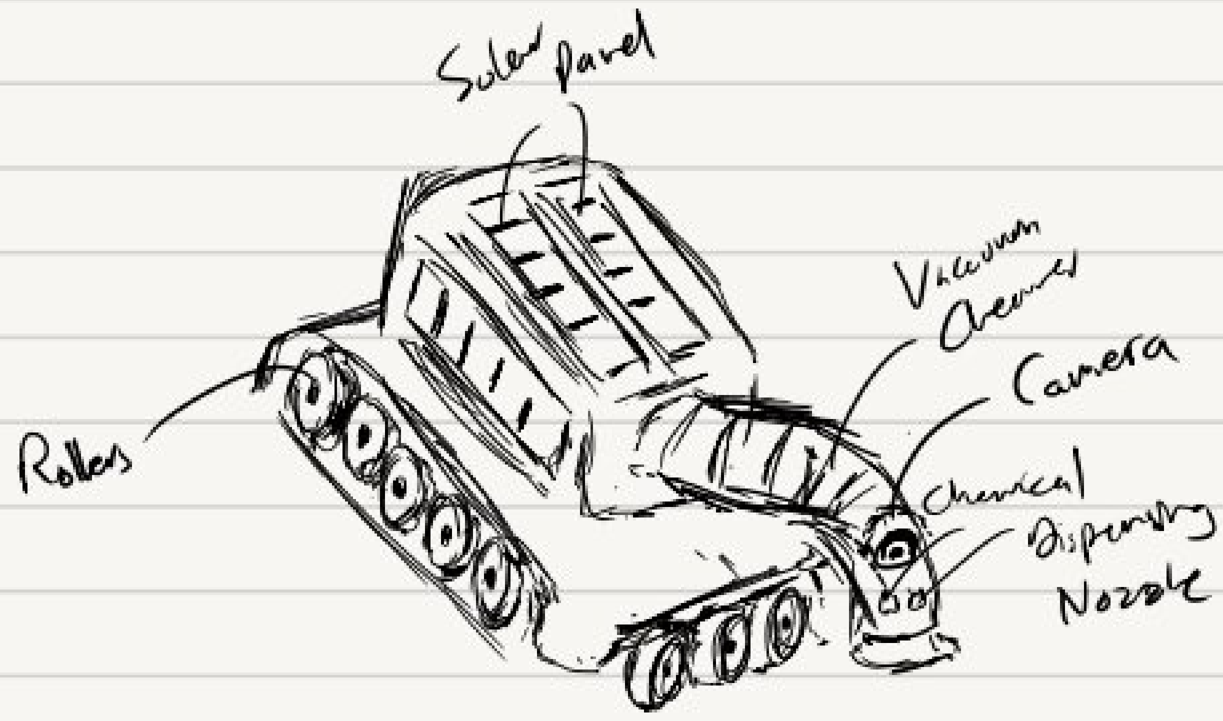
Concept 3

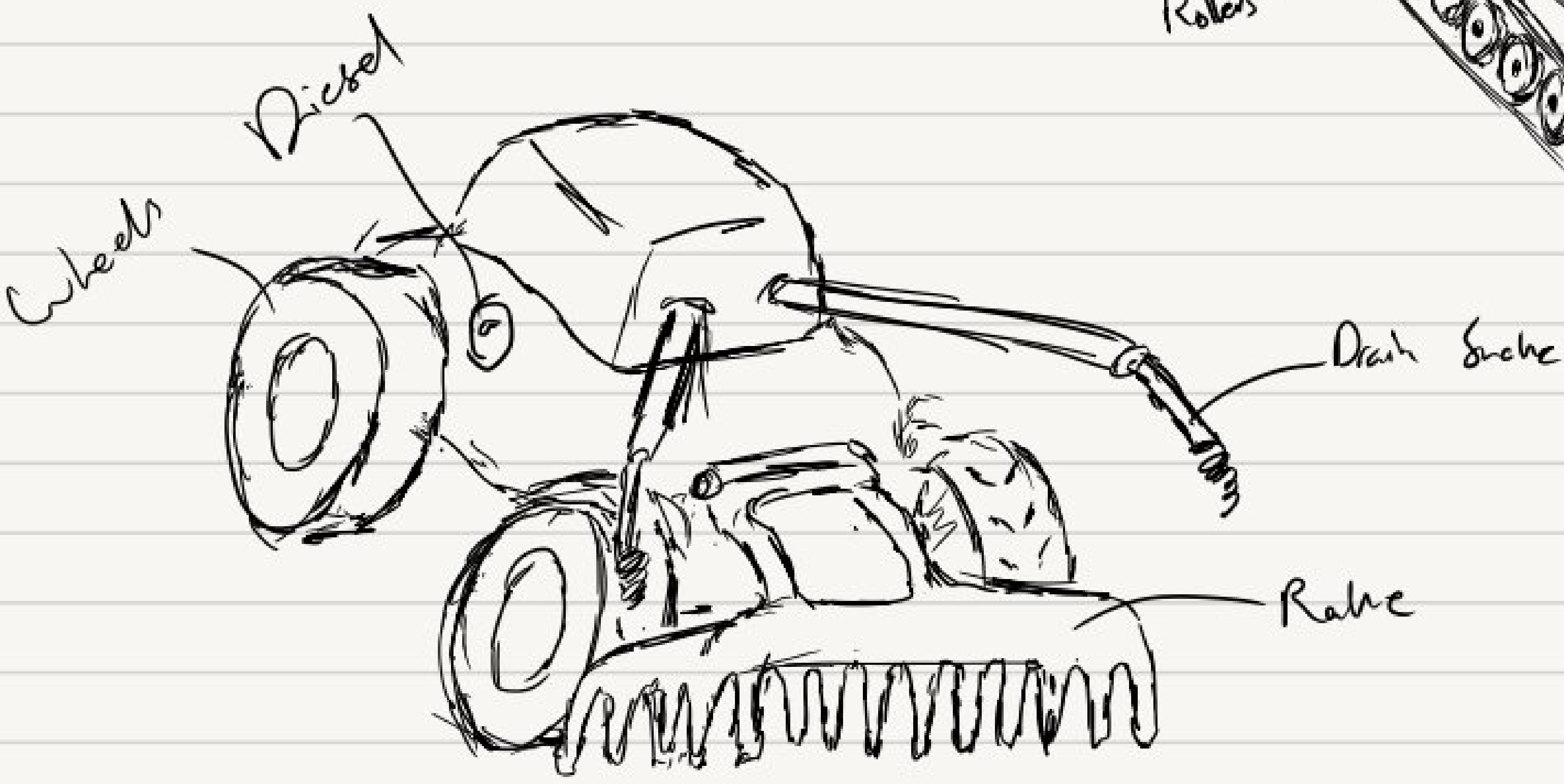


The matrial used:

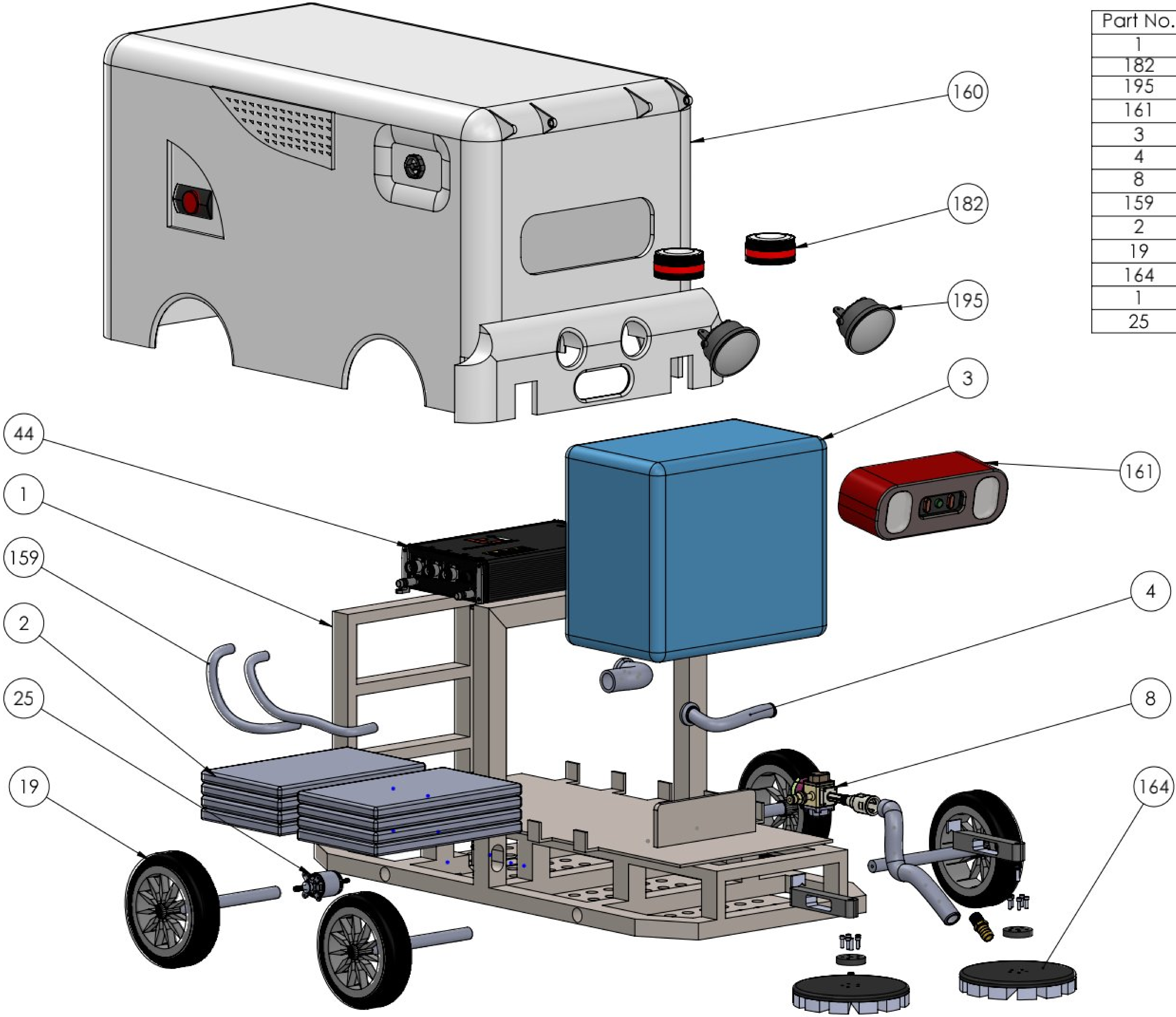
the body will be made from Aluminium and the tires will be make from recycled rubber and for the Rake will use repaired Rake also For the most parts like the lidar and sensors it will be repaired, recycled or salvage (the arms and bolts).


LiDar + Camera
Solar Panels
Claw
Robotic
Arm
Belt
wheels
Rotating
Brush


Solar panel
Vacuum
Cleaner
Camera
Chemical
Dispensing
Nozzle
Rollers


Diesel
Wheels
Drain Snake
Rake

Part No.	Description	Quantity
1	Outer Body	1
182	Hazard Lights	2
195	Headlights	2
161	Camera + Lidar System	1
3	Water Tank	1
4	Water Tubings	2
8	Water Pump & Nozzle Assmebly	1
159	Battery Power Cables	2
2	Battery Packs	8
19	Wheel Assemblies	4
164	Broom Assemblies	2
1	Structural Frame	1
25	Electric Motor	1

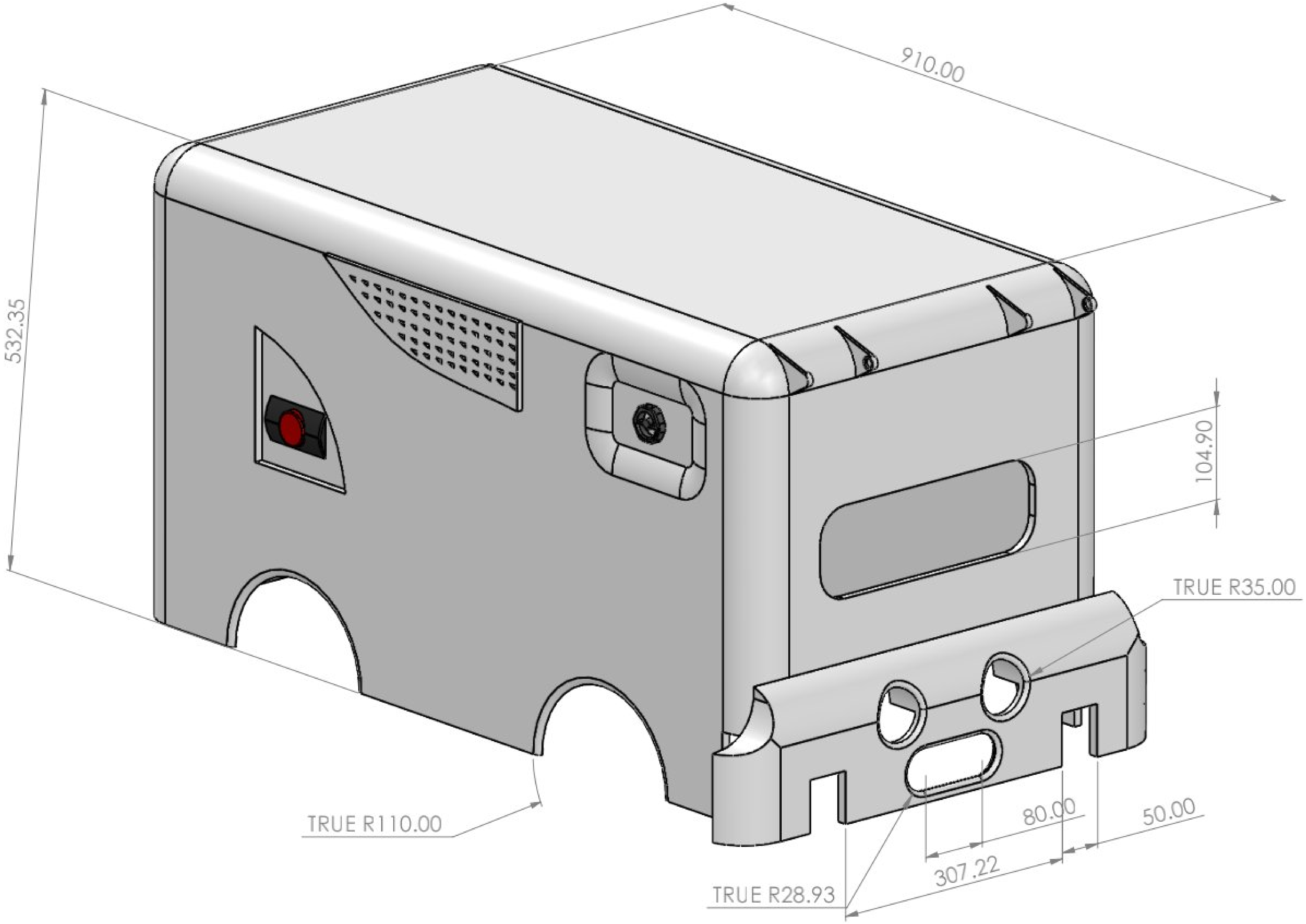


UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING

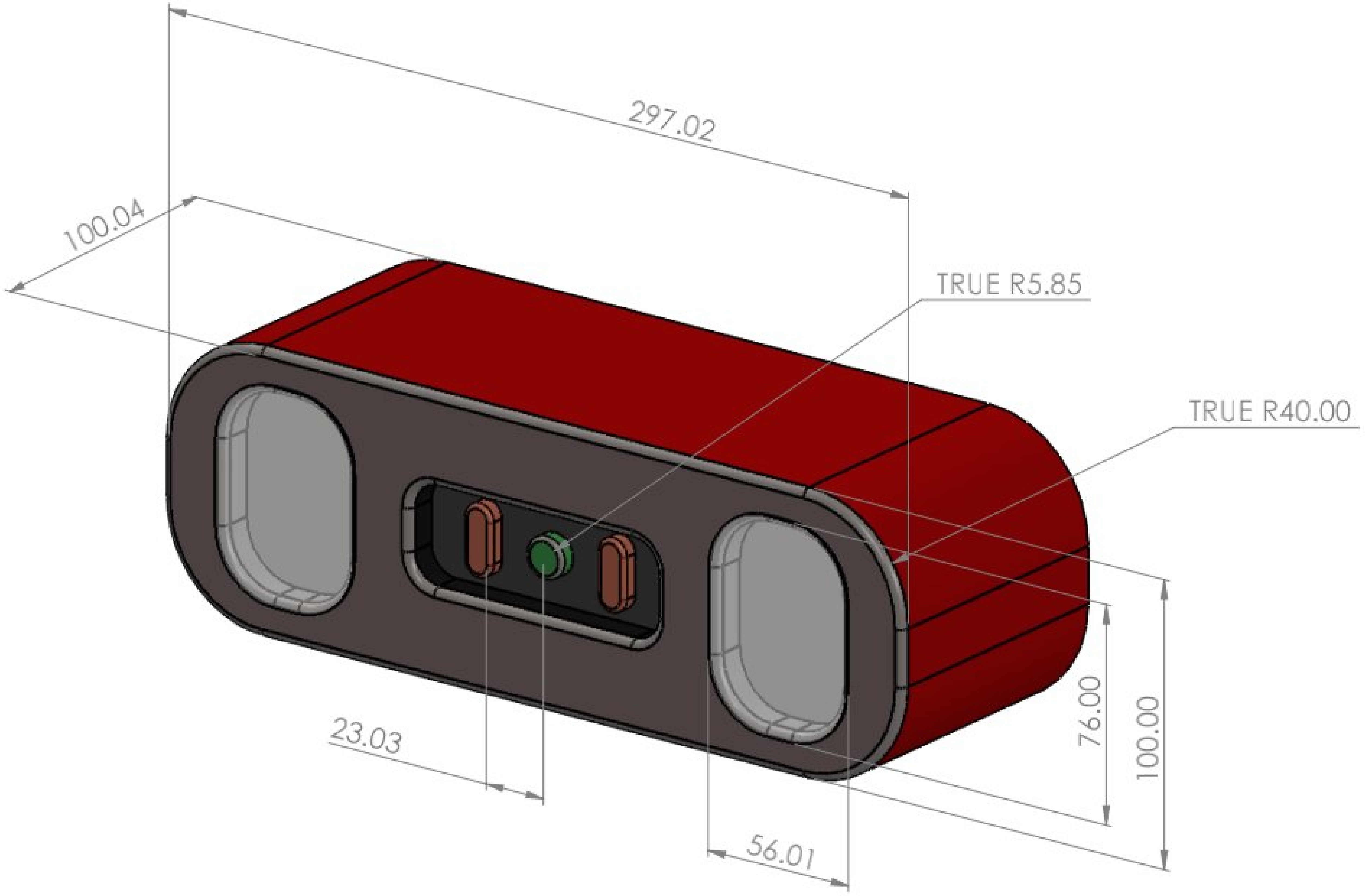
TITLE: EXPLODED VIEW

NAME: PROJECT A`
SECTION: 01

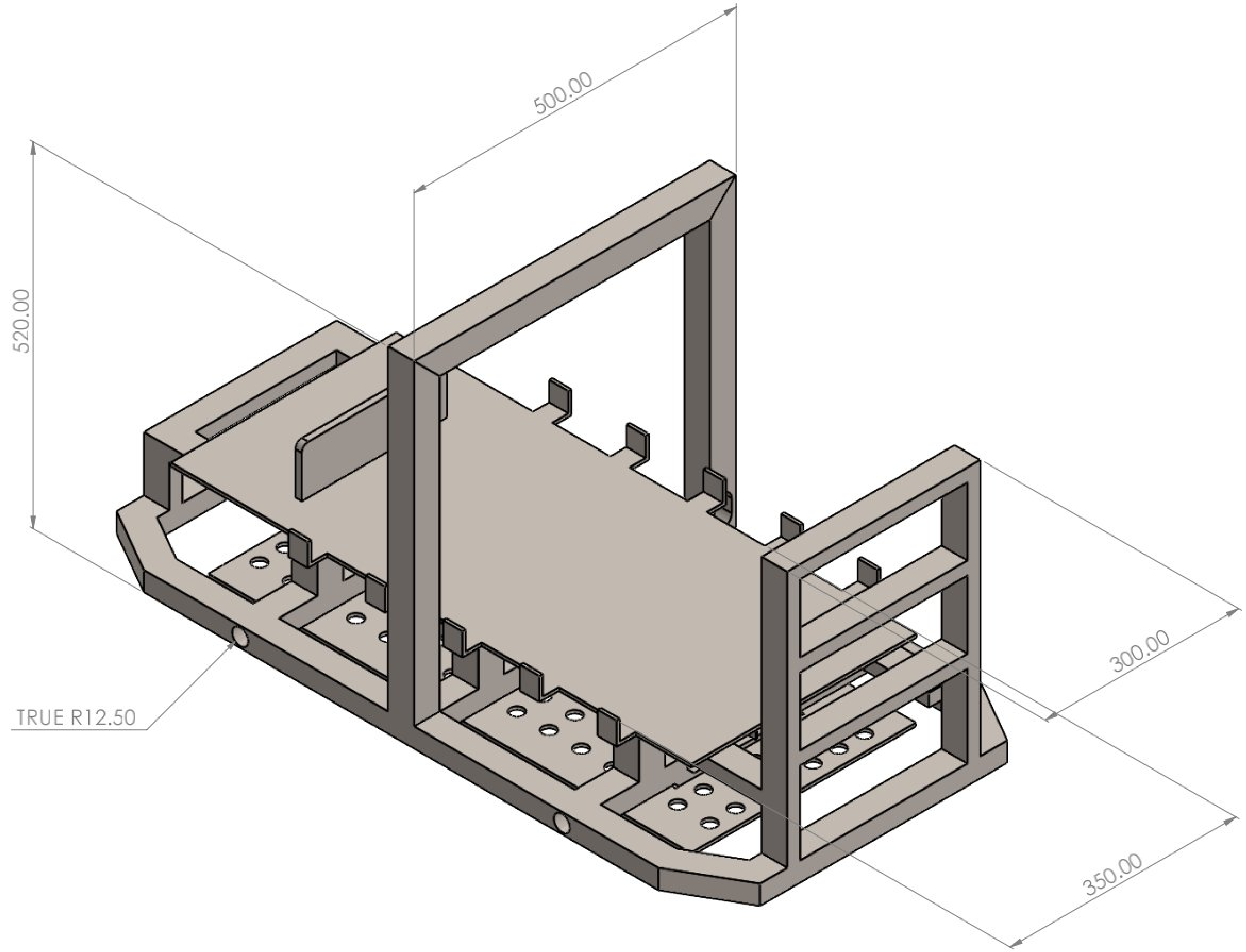
DATE: 24-JAN-2024
SCALE: 1:7



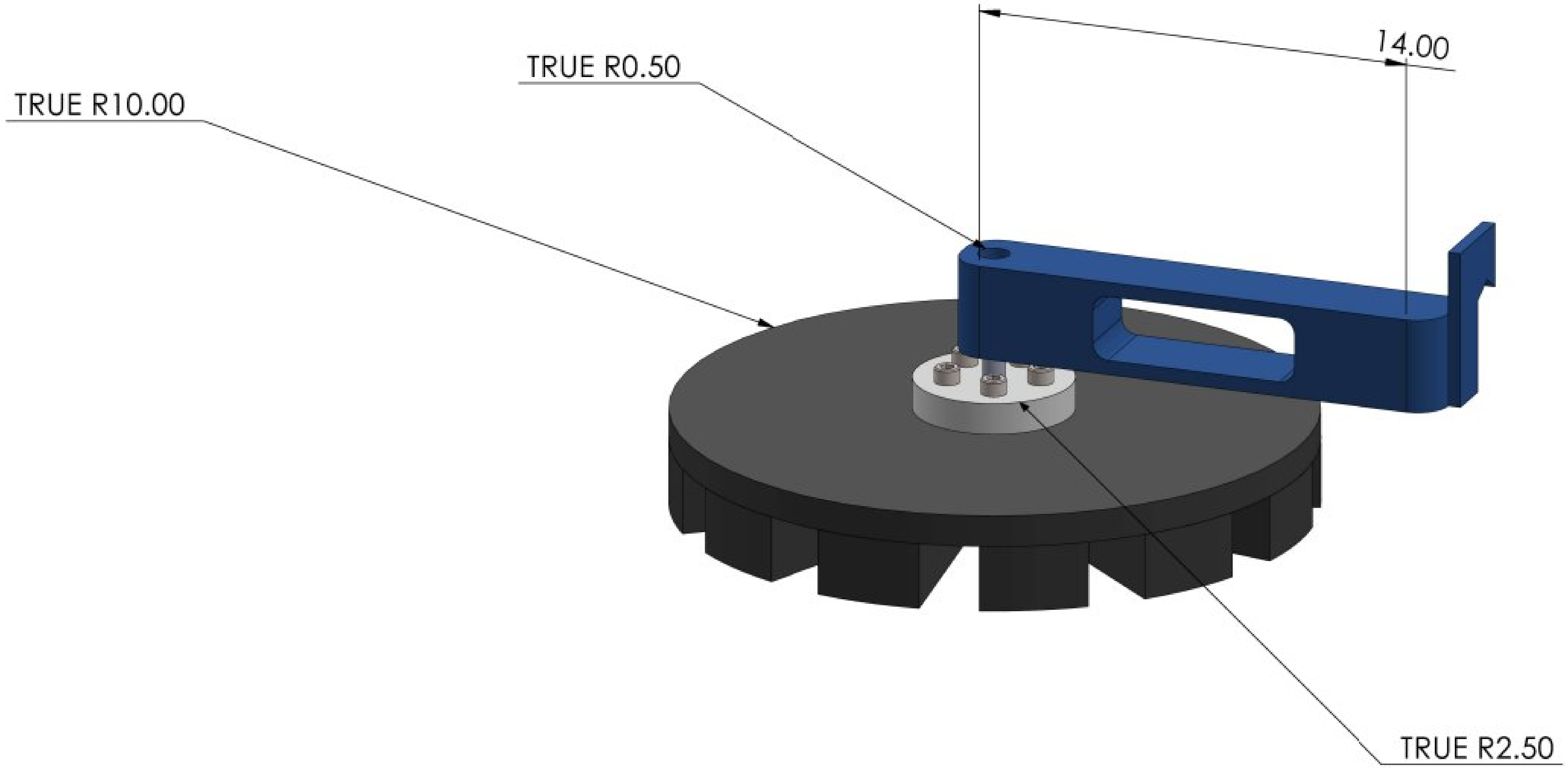
UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: Body	NAME: GROUP 1 SECTION: 01	DATE: 28-JAN-2024 SCALE: 1:5



UTM UNIVERSITI TEKNOLOGI MALAYSIA	UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: CAMERA + LIDAR SYSTEM	NAME: GROUP 1 SECTION: 01	DATE: 28-JAN-2024 SCALE: 1:2



UTM UNIVERSITI TEKNOLOGI MALAYSIA	UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: PID Frame Assembly	NAME: GROUP 1 SECTION: 01	DATE: 28-Jan-2024 SCALE:



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:

FINISH:

DEBURR AND BREAK SHARP EDGES

DO NOT SCALE DRAWING

Group Project

Universiti Teknologi Malaysia

	NAME	SIGNATURE	DATE
DRAWN	Muhammad Arslan	Arslan	01/28/2024
CHK'D			
APPV'D			
MFG			
Q.A			

MATERIAL:

WEIGHT:

TITLE:

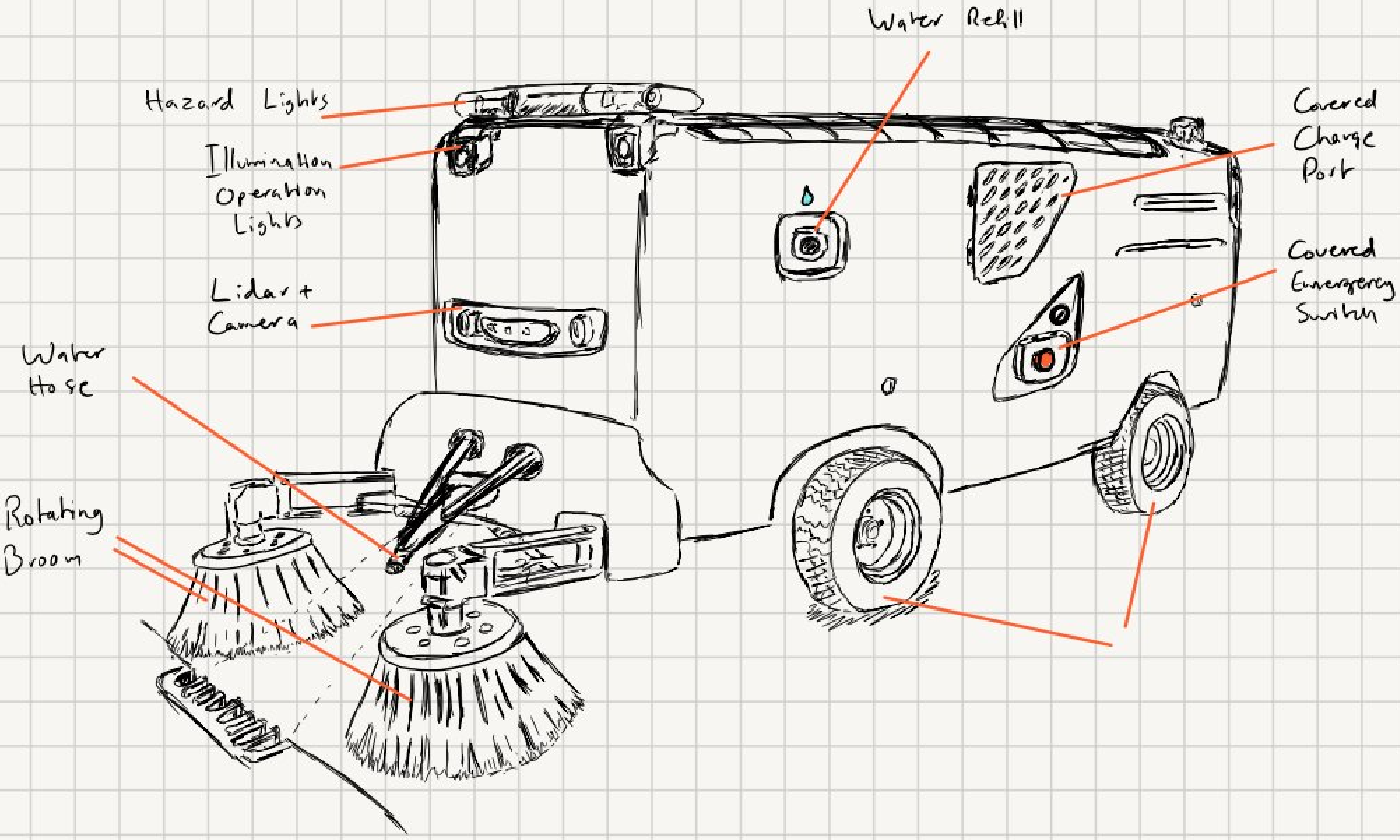
RIGHT ROTATING BROOMS ASSEMBLY

DWG NO.

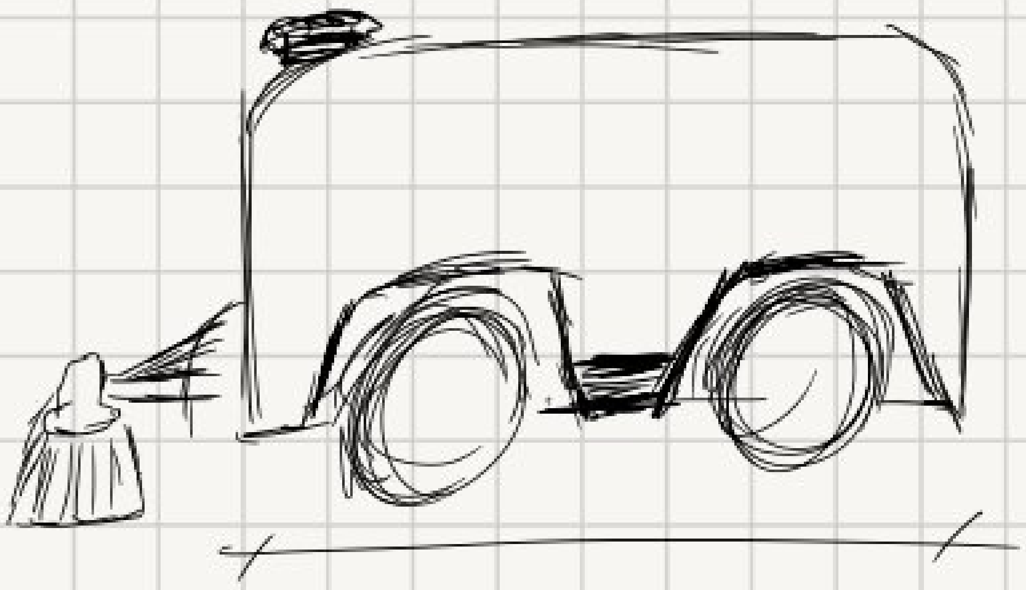
A3

SCALE:1:5

SHEET 1 OF 1

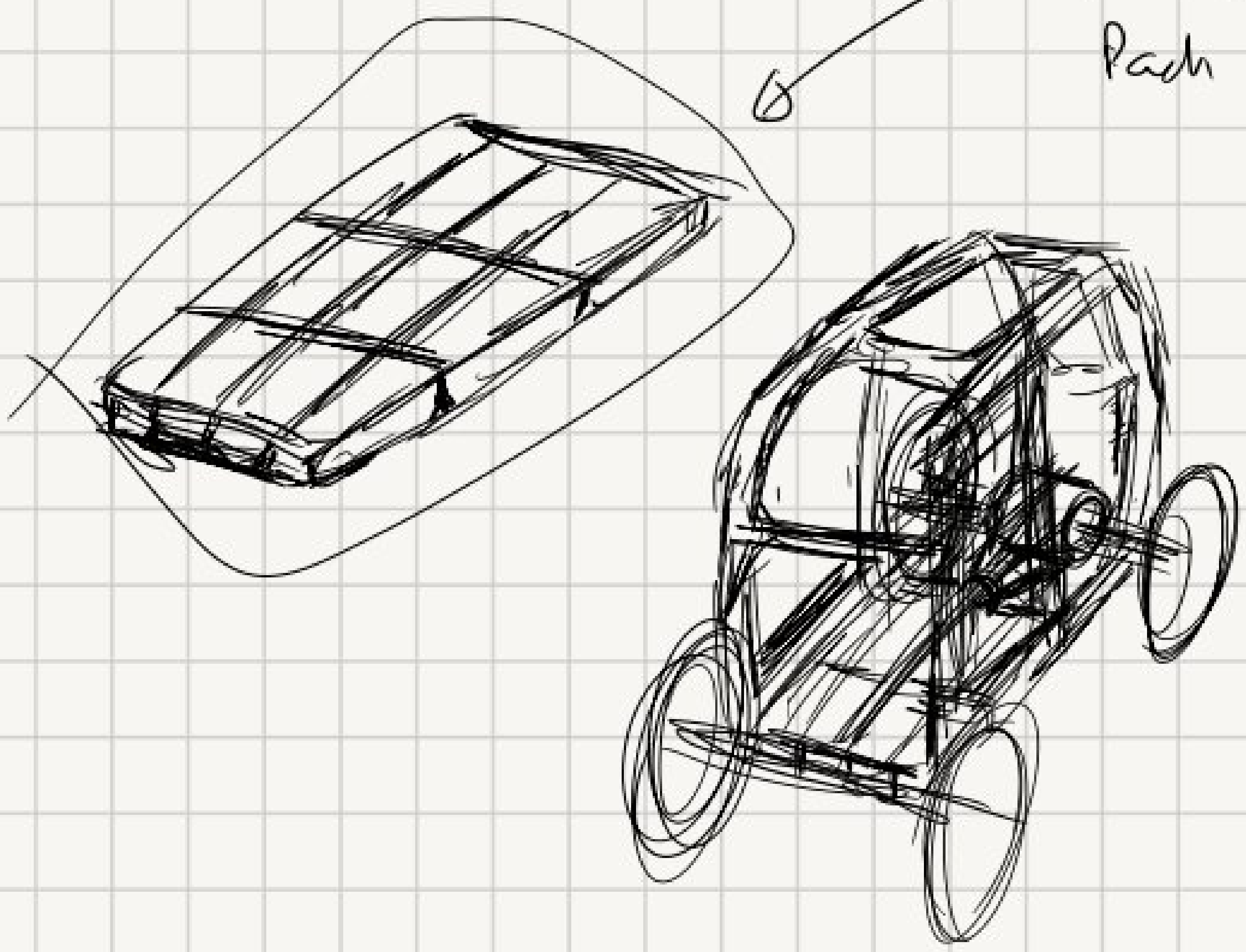


Water Refill
Hazard Lights
Illumination Operation Lights
Lidar + Camera
Water Hose
Rotating Broom
Covered Charge Port
Covered Emergency Switch



30-40 kg

Battery Pack



Frame and Wheels: (mm)