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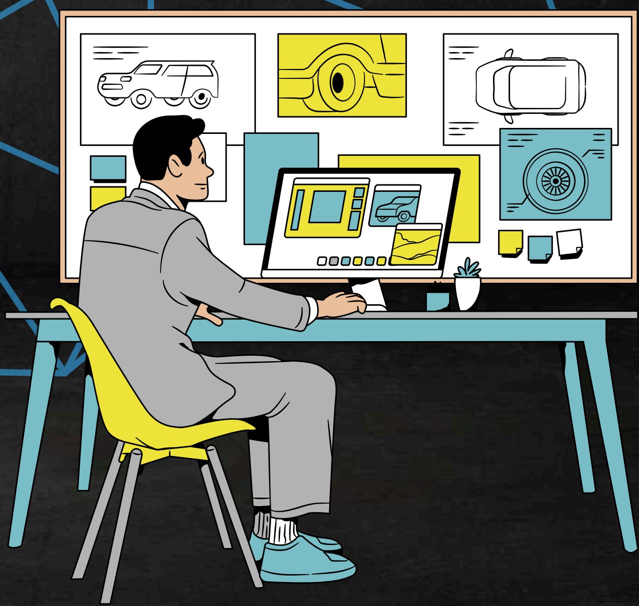
Rooftop Solar-Panel Cleaning Device



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1.0 Introduction

1.1 Problem Background

The global adoption of solar energy has grown significantly, with rooftop solar panels playing a key role in providing clean energy to residential homeowners. However, the long-term accumulation of dust, dirt, and debris often tends to reduce the energy generation output by 20-30%. Manual cleaning, while common, is labor-intensive, time-consuming, and impractical for large or hard-to-access installations. It also poses safety risks and can lead to inconsistent results or panel damage.

To address these issues, there is a growing need for automated cleaning solutions. An Automatic Rooftop Solar Panel Cleaning Device offers a cost-effective, reliable, and scalable way to maintain panel efficiency. By using motors, and cleaning mechanisms, this device can operate autonomously, ensuring consistent energy production while reducing maintenance costs and safety risks.

1.2 Problem Statement

Solar panel efficiency is greatly affected by the accumulation of dust and debris, leading to loss of power generation efficacy and increased maintenance costs. Traditional cleaning methods are inefficient, inconvenient, labor-intensive, time-consuming and therefore expensive. Additionally, existing automated solutions are either expensive or have a complex interface, which makes them impractical or inconvenient for widespread use.

This project aims to design and develop an automated, mobile app controllable, rooftop solar panel cleaning device that is capable of effectively cleaning residential rooftop solar panels mounted on a roof within an incline of 15 to 30 degrees, and notifying its user when the cleaning process is finished; the device operates without human intervention, minimizes water usage, does not affect the existing rooftop solar panel assembly and does not hinder solar panel energy generation.

1.3 Objectives

The main objectives of this project are:

- To design and develop an automated cleaning device for rooftop solar panels that operate efficiently without manual effort.
- To analyze the structural integrity of the system, including bending stress calculations, to ensure stability and durability.
- To minimize energy and water consumption in the cleaning process while maintaining optimal solar panel efficiency.
- To enhance the safety and reliability of the cleaning system by reducing the need for human workers on rooftops.

1.4 Scope

As previously discussed, the scope of this project is limited to the following:

- To design and develop a full-scale rooftop solar panel cleaning device capable of automated cleaning without manual intervention.
- To fabricate and test a scale-model prototype of the rooftop solar panel cleaning device by restricting its size to 1/15th of its original dimensions.
- To ensure the system operates autonomously with minimal human interaction while optimizing the cleaning process.
- To integrate non-abrasive and environmentally friendly cleaning mechanisms that do not compromise the photovoltaic surface
- To develop a lightweight and modular design to facilitate easy installation and maintenance.
- To analyse the mechanical, electrical and structural components of the system to ensure reliability and longevity.

This system aims to provide an efficient and practical solution for solar panel maintanance, addressing the challenges associated with manual cleaning and performance degradation.

2.0 Literature Review and PDS

2.1 Introduction:

Solar panels are employed broadly in the generation of renewable energy, notwithstanding the fact that there is substantial reduction in their efficiency due to dust, dirt, and environmental contaminants. There have been proposals for different ways of automatic cleaning systems to advance energy output through mitigation of the issues and meanwhile reduce maintenance costs. This review discusses various automatic solar panel cleaning methods with regards to effectiveness, limitations, and technological advances.

2.2 Overview of Solar Panels:

Solar panels convert sunlight into electrical energy by the use of semiconductors made from materials like silicon. Solar panels are crucial parts in renewable energy systems and are being used in residential, commercial, and industrial applications. Their efficiency relies on various factors such as material quality, the installation angle of the panels, temperature and maintenance. Common types of solar panels include:

- Monocrystalline Panels which have high efficiency, long service life, but high price point.
- Polycrystalline Panels which are cheaper, but slightly less efficient.
- Thin-Film Panels which are lighter and more flexible, though less efficient compared to crystalline-based panels.

2.2.1 Factors That Can Damage Solar Panels:

Despite their strength, solar panels can be vulnerable to various environmental and operational causes of damage. These include the following:

- Dust and Debris Accumulation which reduces light absorption and efficiency.
- Harsh Weather Conditions like hail, strong winds, and heavy snow can inflict physical damage on the panels.
- Thermal Stress like sudden changes in temperature can cause the solar cells to develop micro-cracks.
- Water Ingress which means poor sealing contributes to moisture penetrating the panels, causing internal damages.
- Bird Droppings and Algae Growth hot spots are created and reduce the panel's efficiency.
- Improper Cleaning Methods like using harsh chemicals or abrasive materials will scratch the panel surface, reducing performance over time.
- Excessive Load meaning placing heavy objects on panels may cause structural damage.

2.2.2 Load-Bearing Capacity of Solar Panels:

Solar panels are designed to bear certain limits of weight according to their construction and mounting systems. Typical residential and commercial solar panels can support:

1. Static Load: Most of the panels bear up to 2400–5400 Pa of pressure, which is 50–100 kg/m².
2. Snow Load: In areas receiving heavy snowfall, solar panels are tested for up to 5400 Pa to avoid damage caused by heavy snow.
3. Wind Load: Properly installed solar panels can bear winds of up to 140 mph.
4. Human Weight: Standing or walking on panels is discouraged as this may cause micro-cracks that reduce long-term efficiency.

2.2.3 Impact of Dust and Soiling on Solar Panel Efficiency:

Research has shown that dust accumulation can reduce solar panel efficiency by 15-30%, depending on the environment (Sulaiman et al., 2020). Dry regions, where dust storms are frequent, face higher efficiency losses (Said et al., 2018). Traditional cleaning methods, such as manual washing, are inefficient specially for large scale cleaning and can be cost ineffective.

2.3 Automatic Cleaning Mechanisms:

Recent works have discussed various automated cleaning methods, including:

a) Mechanical Cleaning Systems

Brush-Based Systems in which the dust is removed effectively by rotating or oscillating brushes powered by motors (Kim et al., 2019), but surface scratches are likely to occur.

Wiper Mechanisms which are similar to windshield wipers, these systems clean effectively, but maintenance needs to be regularly performed (Gupta & Singh, 2021).

b) Water-Based Cleaning Systems

Sprinkler Systems like water spray nozzles spray water over the panels to remove dust (El-Shobokshy & Hussein, 2018). It is effective, but the problem is that water consumption is high in arid regions.

Electrostatic Cleaning meaning high-voltage electrostatic forces lift dust particles without using water (Mazumder et al., 2020), which makes it suitable for dry climates.

c) Robotic Cleaning Systems

Autonomous Cleaning Robots which move across the panel surface using wheels, tracks, or suction mechanisms (Jain et al., 2022). Some integrate AI-based navigation to optimize cleaning patterns.

Drones with Air Blowers which are aerial cleaning robots use pressurized air to remove dust, reducing mechanical wear and water use (Alshammari et al., 2021).

d) Self-Cleaning Coatings

Hydrophobic & Superhydrophobic Coatings which are coatings that repel water and dirt, reducing adhesion (Mahadik et al., 2019).

Photocatalytic Coatings are TiO_2-based coatings that break down organic contaminants under sunlight, minimizing dust accumulation (Luo et al., 2022).

2.4 Patents

To gain a holistic overview of the innovative patented designs that have tackled a similar problem statement, eight patented products were reviewed by our group and classified in terms of advantages, disadvantages and relevancy to this project, The following are the results. Each patent is referred to by its google patent ID and its evaluator,

1. Patent: CN112058842B (Mazen Omar)

The product includes two main elements which are the clamping mechanism and arc-shaped spring supported by the loop bar system. All necessary elements include the water tank and water pump and motor and spray head with a cleaning roller supported by a guide roller system. The device design enables automatic or semi-automatic cleaning operations which both eliminate worker fatigue and provide complete automated solar panel cleaning.

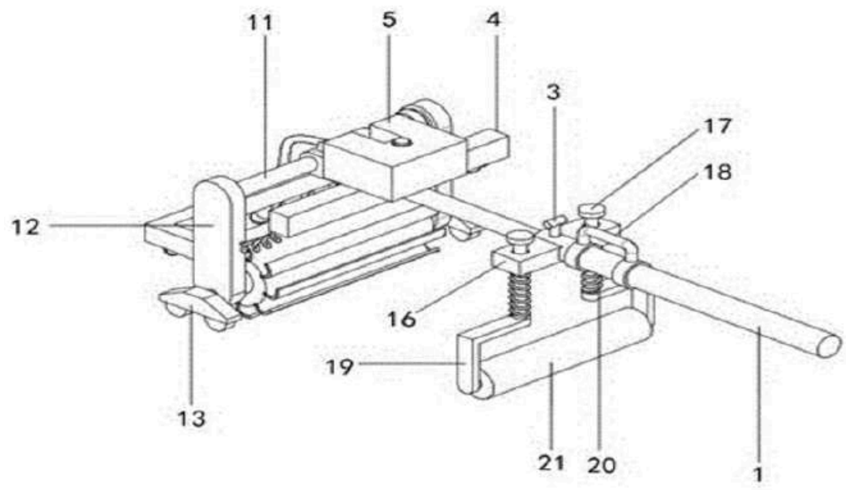


Figure 2-1: Clamping Mechanism

The solar panel cleaning mechanism operates through a rotating brushing system featuring non-woven fabric straps to stop any harm to solar panel surfaces. The integrated water spray system of the device prepares dried stains for cleaning through rolling action by the brushes. The built-in pressure-reducing mechanism allows controlled force application that stops solar panels from receiving harmful pressure amounts. The device allows for height adjustment through its length control feature which enables different installations.

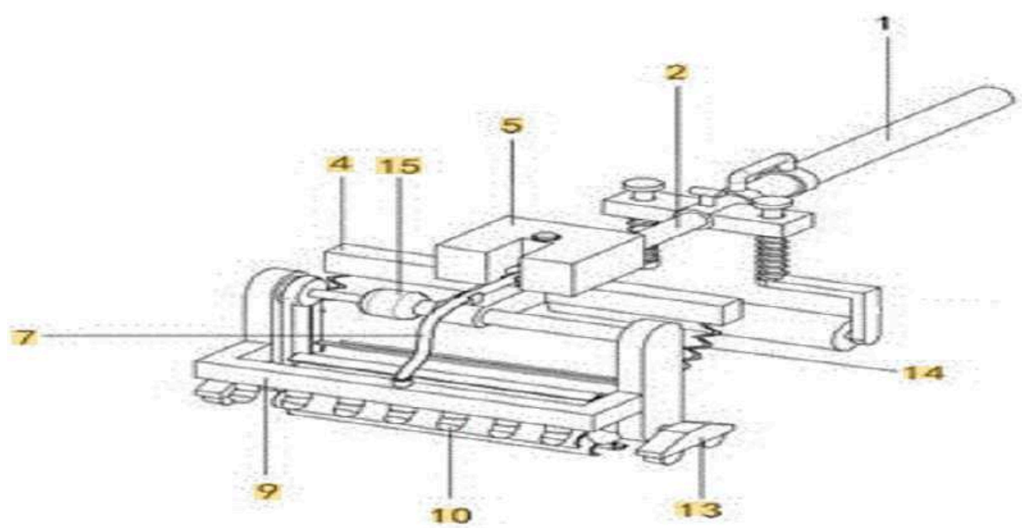


Figure 2-2: Roller Brush Mechanism

Advantages

- The device simplifies cleaning operations by eliminating manual work thus creating a workflow that needs fewer human efforts and less time.
- The water spraying system along with the cleaning roller system produces superior cleaning capabilities.
- A combination of the pressure-reducing device and non-woven fabric roller protects solar panels from delicate surface damage.
- The cleaning device offers adjustability through its adjustable loop bar and movable roller which suits various solar panel angles combined with user heights.

Disadvantages

- The production price of the system along with maintenance expenses rises due to its extra elements such as the motor, water pump, and guide rollers.
- The motor components along with their energy requirements diminish the overall solar panel energy efficiency.
- The design construction might increase system weight thus presenting difficulties for manual assembly in specific circumstances.
- The pump system together with its motor as well as its moving parts needs regular maintenance checks to stop malfunctions while preserving operational efficiency.

Relevancy

The solar panel cleaning device supports our project directly because it resolves main issues which affect solar panel upkeep including efficiency loss and labor requirements and durability problems. Our sustainable solutions project would benefit from integrating the cleaning mechanism to increase solar energy efficiency. This technology implementation allows for the following achievements:

- The operational life of solar panels increases through regular cleaning that removes dust and all external debris.
- A regular automated cleaning system prevents the reduction of energy production while sustaining maximum light absorption.
- The system reduces operating expenses by minimizing human work along with worker physical fatigue while harmonizing with principles that support sustainability and ergonomics.
- The integration of IoT-based monitoring systems must be examined for implementation in predictive maintenance and real-time performance monitoring tasks.

The patent provides an excellent base to create an economical solar panel cleaning system which meets our project requirements.

2. Patent: CN210273955U (Mazen omar)

The device described by the patent functions as an automatic robot for cleaning solar cell panels that enhances both efficiency and convenience within photovoltaic panel maintenance. The device system contains fixed blocks together with threaded rods and a main junction box combined with secondary connection box and servo motors and rotating shafts and cleaning cotton. The device functions using a first servo motor to operate a rotating shaft while the shaft makes the cleaning rod rotate while cleaning cotton remains attached. The panel surface allows movement through the threaded rod because a secondary servo motor controls a gear mechanism. Latches combined with bearings produce a frictionless motion during operation. Through automated system operations the user can remove manual cleaning deficiencies that achieve cost effectiveness and labour efficiency.

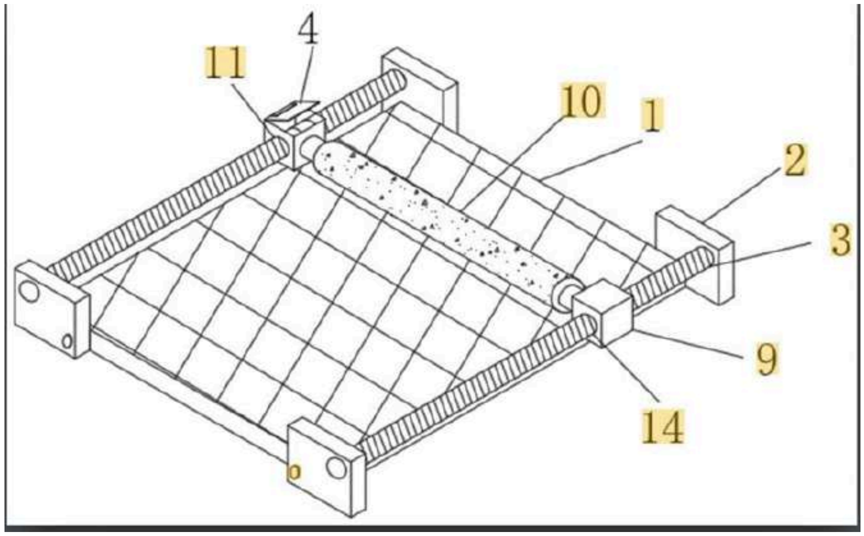


Figure 2-3: Automatic Robot Cleaning Device

Advantages

- Automated processes cut down the necessity of human labor to enhance the operational efficiency of panel maintenance.
- The rotating cleaning cotton enables effective cleaning of dirt and dust from panel surfaces.
- The device leads to long-term cost effectiveness despite significant installation expenses because it minimizes future labor expenses.
- The system uses less water during cleaning operations which lets users lower their environmental impact by decreasing their water consumption.

Disadvantages

- The installation process and setup phase demand large financial investment at the beginning.
- The servo motors together with mechanical components need scheduled maintenance to maintain peak performance.
- Electric motors powering the cleaning device result in slight reductions of overall energy efficiency.
- The cleaning device has limitations regarding its use in solar panel systems featuring irregular or highly angled installation configurations.

Relevancy

The patent shows relevance to our project since it resolves solar panel maintenance problems which ensure continuous energy generation. The implementation of automated cleaning systems follows the objectives to enhance renewable energy system efficiency. The patent's design features with their threaded rod mechanism and servo-driven motion would assist us in creating better upkeep solutions. A similar cleaning system introduced into our solar energy applications would strengthen the performance and sustainability features of our designed solution. Study of this patent's operational guidelines enables us to create innovative developments which combine automation from AI systems with optimized energy usage in cleaning operations

3. Patent: CN220401694U (Mazen Omar)

The proposed solar cell panel cleaning device from the patent aims to boost power generation through photovoltaics by allowing effective cleaning of soiled surfaces on panels. The device includes a cleaning frame with an equipment box and water tank and cleaning roller and wiping roller components. The device reduces waste and improves efficiency through a waterproof seal along with a recycling system for cleaning solution. The solar auxiliary plate functions as an integral part of this device because it uses solar power to operate it in a sustainable way.

Advantages

- Water Conservation Through the Reflux System Enables Recycling Of Cleaning Agent And Improves Both Environmental Sustainability And Reduced Water Consumption.
- Solar panel effectiveness reaches its maximum performance level through the integrated system of cleaning and wiping rollers.
- A motorized system powers the device to move along solar panels thus minimizing both manual operations and requirements for maintenance.
- The solar auxiliary plate integrated into the product enables self-power generation which optimizes energy efficiency.
- The waterproof seal of the device protects solar panels from cleaning solution leakage to minimize their surface damage.

Disadvantages

- Multiple elements such as the reflux system and waterproof seal may make the device more complex to produce which affects its manufacturing expenses and technical difficulty.
- Operation of the device depends on routine maintenance for motor and cleaning roller functionality alongside water recycle system performance.
- The device implements water recycling but the onboard water reservoir needs regular refilling particularly when applied at large solar panel array installations.
- The solar auxiliary plate loses its effectiveness when low light or cloudy conditions block sunlight from reaching the panel.

Relevancy

The patent presents innovative solutions to preserve solar panel efficiency that directly supports our project because maximizing energy output depends on it. Our sustainable energy project could incorporate automated cleaning methods that are explained in this patent. Our system needs to integrate cleaning systems like the ones presented in this patent to boost solar panel efficiency and extension according to design specifications. The framework for water recycling within the mechanism fulfils our sustainability mission because it cuts down on resource consumption. The analysis of this patent will help us develop implementation strategies that merge automatic maintenance with sustainable energy features for our project while maximizing its operation strength through an environmentally conscious design.

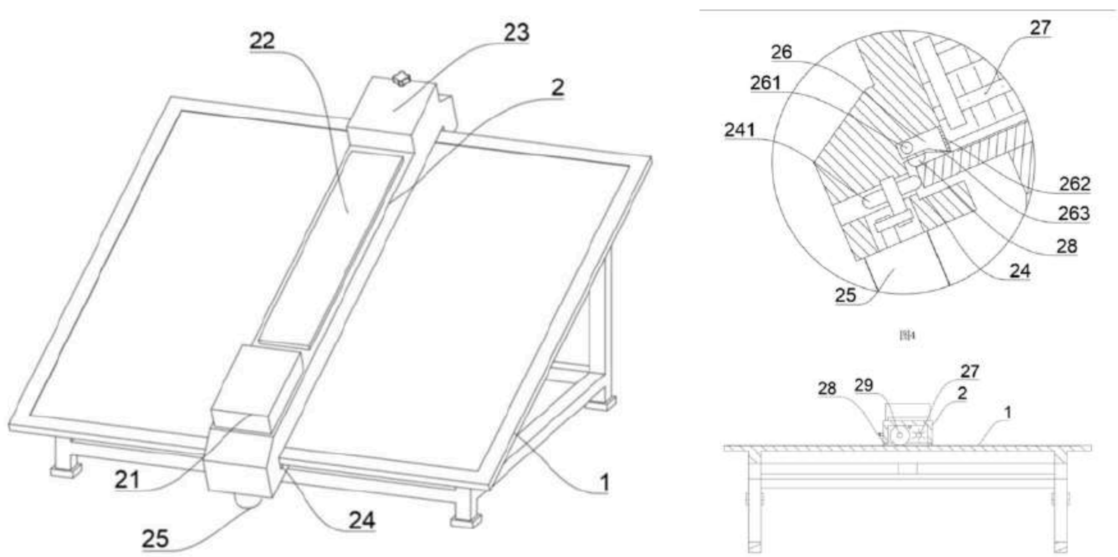


Figure 2-4: Patented Solar cell panel cleaning device schematic diagrams.

4. Patent: EP2529162B1 (Moaz)

The patent is titled, Self-Cleaning Solar Panel System with Conductive Coating and Sensor-Based Control, and provides a new idea with a new approach on how to maintain solar panels efficiency by using self-cleaning mechanisms as well as feedback sensors. The invention uses a conductive coating layer, different environmental sensors, and an electromagnetic cleaning system that gets powered by solar energy or an external battery.

The solar panel uses and integrates several sensors, such as luminosity, temperature, and humidity sensors.These sensors collect and provide information to the system, allowing proper response to environmental factors and changes. The surface of the panel is also coated with a coating that is conductive in nature in different geometric patterns. A transparent isolation layer is placed on the conductive surface while providing maximum light transmission.

The conductive coating is driven by four DC motors that produce a pulsing electromagnetic field. The fields' purpose is to repel dust, sand, and other impurities from the panel surface. The system can also be controlled to produce heat to stop ice buildup. A microcontroller is used to control the operation of the cleaning mechanism depending on the info provided by the sensors. The system optimizes performance by turning on the cleaning cycle only when needed, reducing energy consumption. The system can utilize power directly from the solar panel or an external battery.This double power approach ensures continuous operation even during days that don't have enough sunlight.

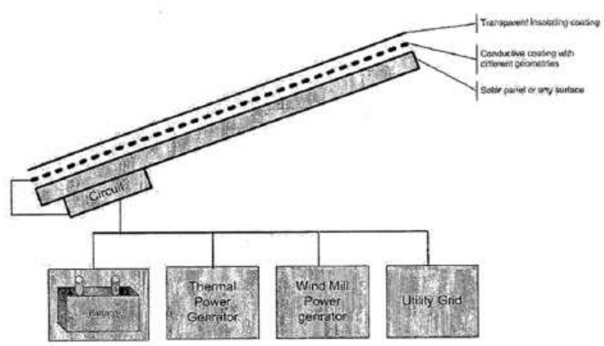


Figure 2-5: System Layout

Advantages:

The self-cleaning mechanism helps maintain the solar panels efficiency by maintaining the solar panel cleanliness against various factors. Also, the Sensor-based control minimizes the need for manual human interference. Furthermore, reducing dirt and ice accumulation helps protect the solar panel from environmental degradation. In addition to that the ability to run on solar power makes the system independent and eco-friendly. Finally, the solar panel can have different configurations for the conductive coating to accommodate different solar panel shapes and dimensions.

Disadvantages

The efficiency of the system during extended low-sun periods or extreme weather conditions may need to be carefully managed. Secondly, the combination of several sensors, a microcontroller, and a conductive coating can make the production costs on the higher side. Also, the long-term stability of the conductive coating and its resistance to environmental conditions needs to be tested further. Finally, the pulsing electromagnetic field might interfere with other electronic devices like the sensors which will affect the sensor input data.

Relevancy

This technology can significantly improve efficiency in desert regions where dust accumulation is a huge concern. Also, self-cleaning panels help reduce the maintenance costs and owners' effort for homeowners. Furthermore, the ice-melting feature makes it ideal for solar panels in snowy regions. Finally, the automated cleaning mechanism ensures reliability in locations with limited maintenance access. The technology provided in this patent provide a new and effective solution to help maintain solar panels in different environmental conditions, it has many advantages over the current cleaning and maintenance options but it still needs further testing to ensure its proper work after extended periods of time.

5, Patent: KR102373790B1 (Shammim)

Patent KR102373790B1 presents an automated solar panel cleaning system designed to enhance efficiency, reliability, and sustainability in solar energy generation. It introduces a self-operating cleaning device that moves autonomously across solar panels, detecting contamination levels using sensors and optimizing cleaning cycles with fluid spray, brushes, and a wiping mechanism. The system minimizes manual labor, reduces water and energy consumption, and ensures consistent cleaning. The patent introduces an automated solar panel cleaning system that operates independently, identifying dirty areas on solar panels and cleaning them effectively using fluid spray, brushes, and a wiping system. The system is mobile and can move across multiple panels, ensuring a consistent cleaning process without human intervention.

The system consists of a cleaning unit that integrates fluid spraying, brushing, and wiping mechanisms. The fluid spray loosens debris, the brush scrubs off tough dirt, and the wiping unit removes excess fluid and fine particles, leaving the panels clean and dry. A mobility system allows the device to move autonomously using motorized wheels or rail-guided movement. The sensor-based control system detects dirty areas by analyzing solar power output, triggering targeted cleaning to optimize energy and water use.

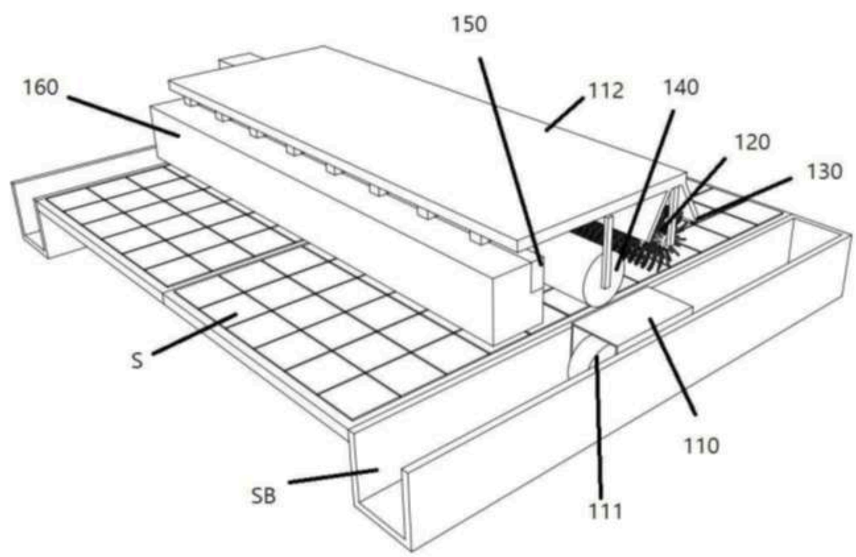


Figure 2-6: Solar Panel Cleaning Unit

A wireless communication module enables real-time monitoring and coordination of multiple cleaning units, making the system scalable for large solar farms. It is powered by a battery, rechargeable through solar energy or an external source, and includes a fluid tank for efficient cleaning solution management.

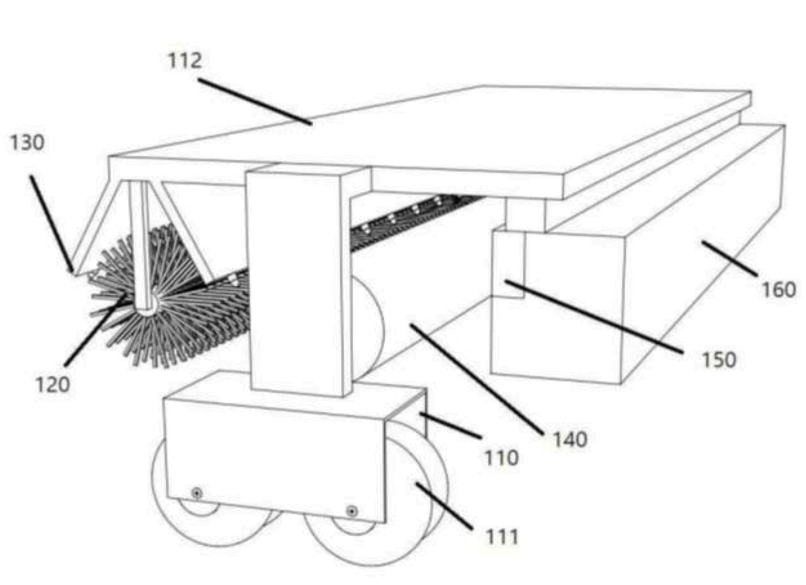


Figure 2-7: Side View of Cleaning Unit

Figure Legend:

10: body body

20: brush part

30: fluid injection unit

32: nozzle

40: mop part

41: rotating body

42: mop

43: rotation support

31a, 31b: spray body

100: solar panel automatic cleaning device

110: body body

111: wheel part

120: brush part

130: fluid injection part

140: mop part

150: battery unit

160: fluid tank

Advantages

This system eliminates manual labor and reduces operational costs, making solar panel maintenance safer and more efficient. The smart contamination detection ensures cleaning only where necessary, saving water and energy. The modular and scalable design suits various solar installations, from rooftop panels to large solar farms. Remote monitoring via wireless communication allows users to track cleaning cycles and system performance.

Disadvantages

The high initial cost of sensors, motors, and automation may be a barrier to adoption. Maintenance is required for the brushes and wiping components, which may wear out over time. The system may also struggle with hardened dirt, such as bird droppings, requiring occasional manual intervention. Additionally, extreme weather conditions may affect performance, requiring weather-resistant materials and design improvements.

Relevancy

Since we are developing a rooftop solar panel cleaning device, this patent provides valuable insights and innovations that can directly enhance our project. The multi-stage cleaning mechanism (fluid spray, brushes, and wiping) could significantly enhance our cleaning efficiency. Automated movement systems, such as motorized wheels or rail guides, could improve coverage and mobility in our design.

The sensor-based contamination detection can be integrated to optimize cleaning cycles, ensuring cleaning only when necessary. Wireless communication features suggest future scalability, allowing remote monitoring and IoT-based automation for commercial applications. The modular approach supports future expansion, enabling multiple units to function together on large solar arrays For our rooftop solar panel cleaning project, this patent provides key inspirations in cleaning efficiency, automation, and movement strategies. By incorporating its best features, we can develop a more effective, scalable, and commercially viable cleaning solution.

6. Patent: CN221806887U (Taraq)

The patent CN221806887U introduces an innovative approach to maintaining solar panel efficiency through automated cleaning mechanisms. The invention employs a motorized track-guided system, a rotating brush, and a controlled water-spraying mechanism to ensure effective dust and debris removal. This review provides a comprehensive analysis of the product. The selected patent, CN221806887U, describes a solar panel cleaning device designed to automate the cleaning process of photovoltaic panels. The device consists of a mobile cleaning mechanism that moves along the surface of the solar panels, utilizing a rotating brush and water-spraying system to remove dust and debris. The movement is controlled by a motorized system that ensures effective coverage of the entire panel. The design incorporates a track-guided cleaning system to maintain stability while operating.

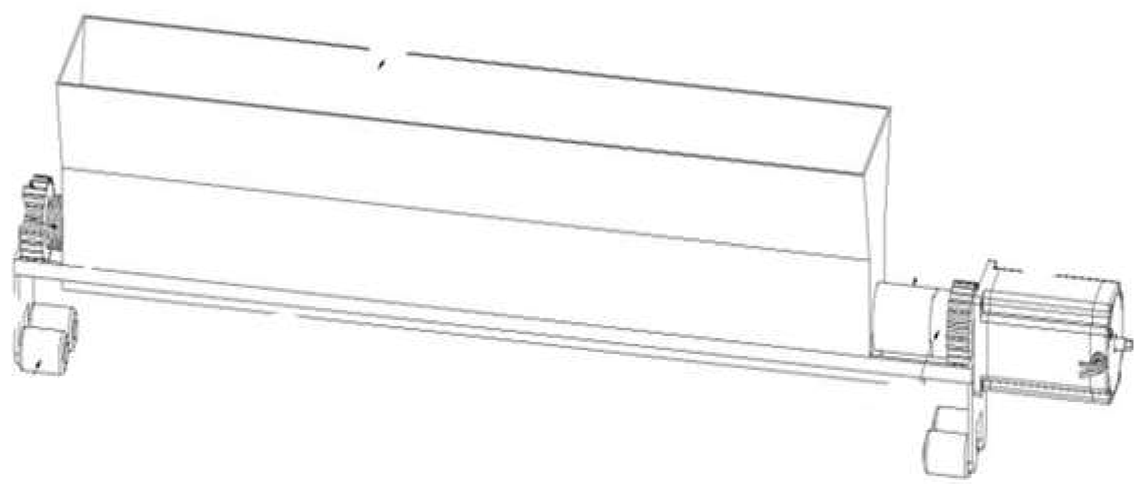


Figure 2-8: Overall structure of the solar panel cleaning device, illustrating the track-guided mechanism and automated cleaning components.

Advantages

- **Automated Cleaning:** Reduces the need for manual labour, improving efficiency and consistency.

- **Optimized Water Usage:** The device integrates a controlled water-spraying mechanism to minimize water wastage.

- **Enhanced Cleaning Efficiency:** The rotating brush ensures that dust and debris are effectively removed, maintaining solar panel efficiency.

- **Structural Stability:** The track-based system ensures smooth movement and prevents misalignment during operation.

- **Low Maintenance Requirements:** The design minimizes wear and tear, increasing the lifespan of the system.

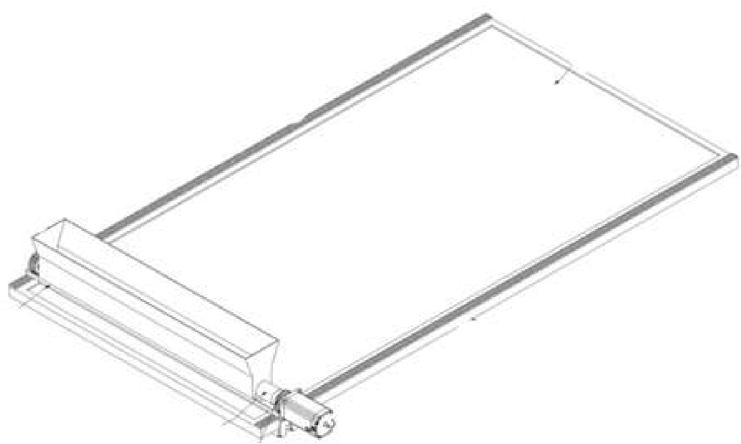


Figure 2-9: Track-guided motion system ensuring stability and smooth movement during cleaning operations.

Disadvantages

- v **Limited Adaptability:** The system is designed for a specific panel size and may not be easily adjustable for different solar panel configurations.

- v **Complex Installation:** Requires pre-installed tracks, which might not be feasible for all rooftop structures.

- v **Potential Mechanical Failures:** Moving parts such as motors and brushes may require periodic maintenance or replacement.

- v **Dependency on Water Supply:** The system relies on water spraying, which may not be suitable for regions with water scarcity.

Relevancy

Our group project focuses on designing an **automatic rooftop solar panel cleaning device** that aims to enhance the efficiency and longevity of photovoltaic panels. The patent provides valuable insights into potential **mechanisms for automation, cleaning techniques, and track-guided movement**, which can be adapted to improve our design.

Key Benefits for Our Project Development:

1. **Incorporation of a Track System:** We can integrate a similar guided track system to ensure controlled and precise movement across the panels.
2. **Brush and Water Mechanism:** The rotating brush and controlled water spray concept can be optimized to reduce water consumption while maintaining cleaning efficiency.
3. **Motorized Motion Control:** The motorized movement system in the patent can help us refine our own motor selection for effective energy use.
4. **Structural Improvements:** Learning from the limitations of the patent, we can explore ways to make the system adaptable to different solar panel configurations.
5. **Alternative Cleaning Methods:** To address the water dependency issue, we can incorporate dry-cleaning technologies such as electrostatic dust removal.

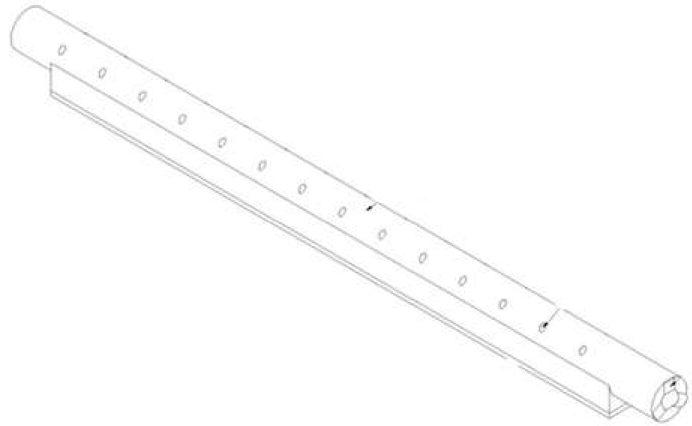


Figure 2-10: Brush and water spraying mechanism

The reviewed patent provides a strong foundation for developing an efficient and reliable solar panel cleaning device. By analysing its **advantages and drawbacks**, our project can implement **improved automation, adaptable designs, and alternative cleaning methods** to enhance performance and usability. These insights will contribute significantly to the successful implementation of our rooftop solar panel cleaning device.

7. Patent: CN113042409A (Arslan)

Patent CN113042409A introduces an innovative and modular solar panel maintenance device capable of automated cleaning that removes the need for manual interference.. The solar panel maintenance device is used to manage and maintain a solar panel unit that has several solar panels with panel surfaces grouped in an array. It has the following key features:

- A main body device with a maintenance mechanism to undertake solar panel unit maintenance; and
- A moving mechanism for moving the apparatus main body along the plate surface
- Two maintenance states that it can freely switch in and out of

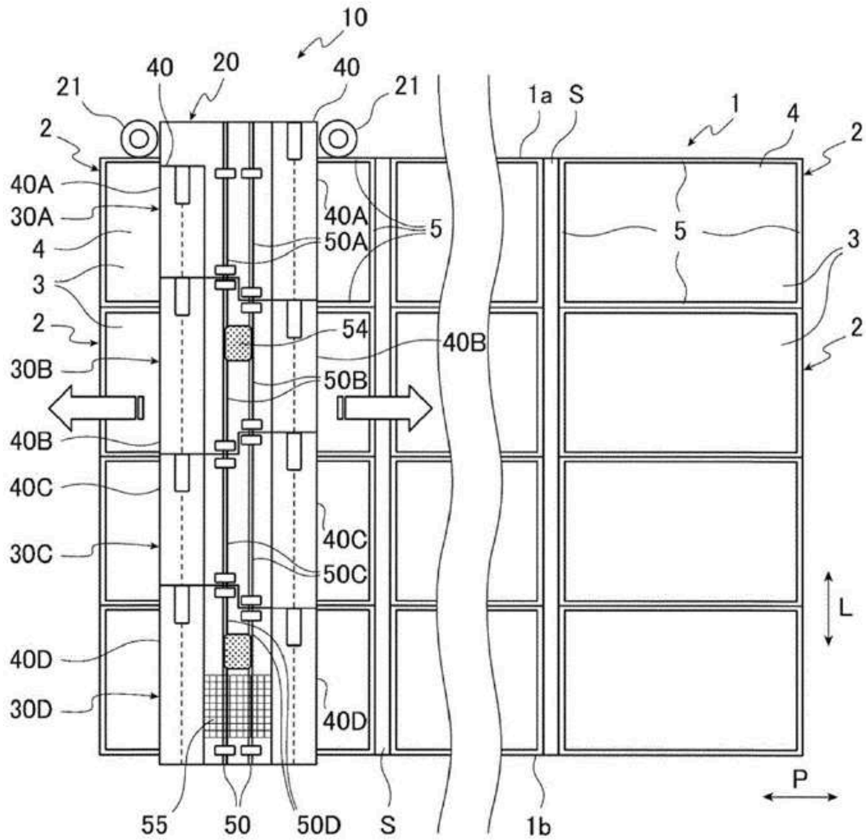


Figure 2-11: Modular Solar Panel Maintenance Device

As illustrated in the figure above, the solar panel maintenance device has a moving mechanism that moves the main body of the apparatus along the plate surface. It can switch between a first maintenance state and a second maintenance state. In the first maintenance state, a connecting body connects and integrates several divided bodies with the maintenance mechanism along the plate surface in a largely single direction. The first body is used for the movement while the following connecting bodies perform the maintenance work on the panel such as scrubbing, polishing or washing etc.

In contrast, the figure below showcases the second maintenance state of the device.

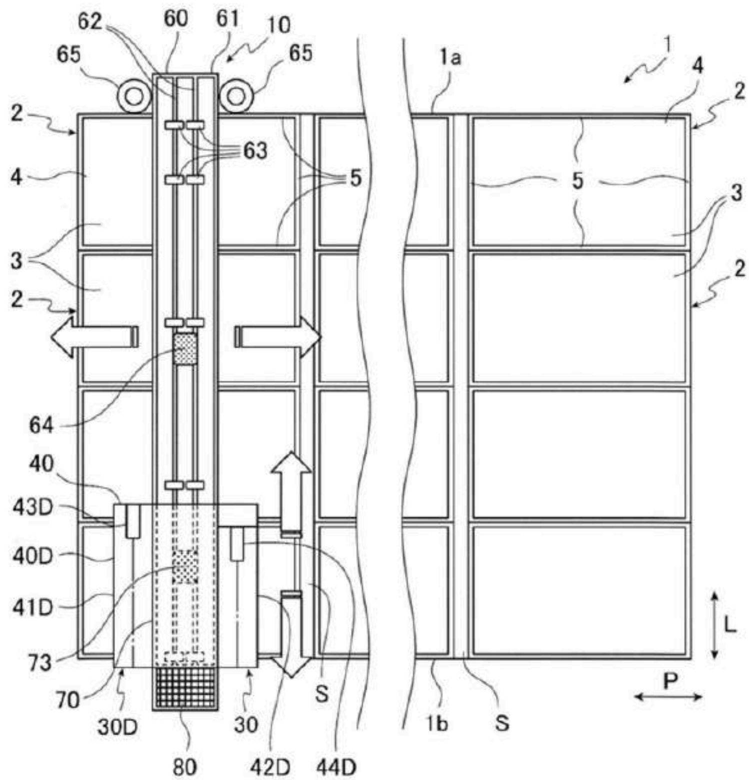


Figure 2-12: Modular Second Maintenance State

In particular the primary function of the two modular states is to accommodate different panel arrays. An array with many large solar panels will require the first state to clean thoroughly and efficiently, whereas a solar panel area consisting of only one or two panels can easily be cleaned using the modular single body state to save on energy costs.

Advantages

- Uses a secure rack and pinion design to safely clean the panels preventing damage to the surface.
- Capable of adjusting the number of connecting bodies to adapt to different solar panel arrays,
- Device massively reduces the need for manual cleaning of solar panels
- Efficient and regular cleaning is possible using the standardized cleaning bodies used in the device that each cover a uniform area

Disadvantages

- Device requires a very complex assembly to utilize properly
- If the solar panel array is changed, the device must be reconfigured to support proper cleaning which is time consuming.
- Manufacturing costs are very high due to modular parts
- Repairability is low due to many small connecting bodies which can malfunction and require replacement.

Relevancy

The patent introduces a new and innovative modular grid approach to cleaning large scale solar panel arrays that are often utilized on residential rooftops to maximize energy generation. Though the patent is highly focused on its modular design and does not tackle the cleaning aspect well as compared to the other patents, it provides a fully adaptable solution of modular cleaning bodies capable of theoretically cleaning any size of panels as long as enough cleaning bodies are available. Despite its shortcomings, the patent highlights the need of an adaptable design for the solar panel cleaning device, prompting our group to investigate the possibility of creating a device capable of cleaning panels in an array fashion.

8. Patent: CN108405383B (Ahmed)

This patent describes a design that utilizes various movement mechanisms and stability features to provide efficient cleaning of the solar panel.

The solar panel cleaning device is designed for efficient, automated operation. The device moves in two degrees of motion, longitudinal and lateral directions to ensure the entire area of the panel is covered. To enable that, a longitudinal mechanism powered by a DC motor, which drives a lead screw and balance bar group, is implemented. This ensures precise and smooth motion of the device across the panel. Moreover, the design moves along the panel in the lateral direction by installing rack rails at the solar panel mounting bars with which a motor-powered movement gears mesh to provide precise and stable movement. In addition, it features a raising mechanism to lift the rollers off the photovoltaic panel for stowage when idle. Sensors and UV light inspection systems are adapted in appropriate locations to aid in the precise movement of the device and ensure all spots of the panel are sufficiently cleaned. The device is also equipped with a wireless charging module to keep it powered and a self-locking mechanism to prevent accidental movement; making it both reliable and safe.

Advantages

- Automation convenience which omits the need for manual labor and provides consistent cleaning.
- Effective cleaning due to the combination of a brush and sponge to clean dust and debris off the panel.
- A built-in water tank ensures efficient water usage during cleaning.
- Movement mechanism uses railings which prevent skidding which could damage the panel. Additionally, soft bristle brushes are used in cleaning.
- Feedback loop using UV inspection ensures cleaning efficacy is consistent and reliable.
- Self-Locking mechanism ensures the device is stable when idle or during power loss, making it safer.
- Design is easy to install and utilizes a modular design for ease of maintenance.

Disadvantages

- Design uses too many moving parts, which increases points of failure.
- Initial investment cost might make it unattractive and reduce its competitive advantage compared to simpler semi-automatic solutions.
- Using lead screw and other heavy mechanisms might make it unsuitable/unsafe for installation in some solar panel assemblies.
- Environmental factors can highly affect its functionality. Does not consider operation in harsh conditions.
- Design uses two motors, which consumes a significant amount of power, reducing its power consumption efficiency.

Relevancy

The design implements a plethora of beneficial concepts that are relevant to our design process. In particular, movement mechanisms adopted which inherit great stability may be a great source of inspiration to be adopted into the Heliocentric cleaning device. This is especially due to the incline of roofs on which our design is expected to operate on; hence using rack rails eliminates the issue of skidding. Learning from the weight disadvantage of this patented design, the Heliocentric design shall ensure a lightweight construction which is even more crucial given the gravity resistance during movement up the slanted roof. The lift-off mechanism might not be necessary as moving the panel in the lateral direction off of the panel might suffice, hence this mechanism only adds weight, which does not align with our product requirements.

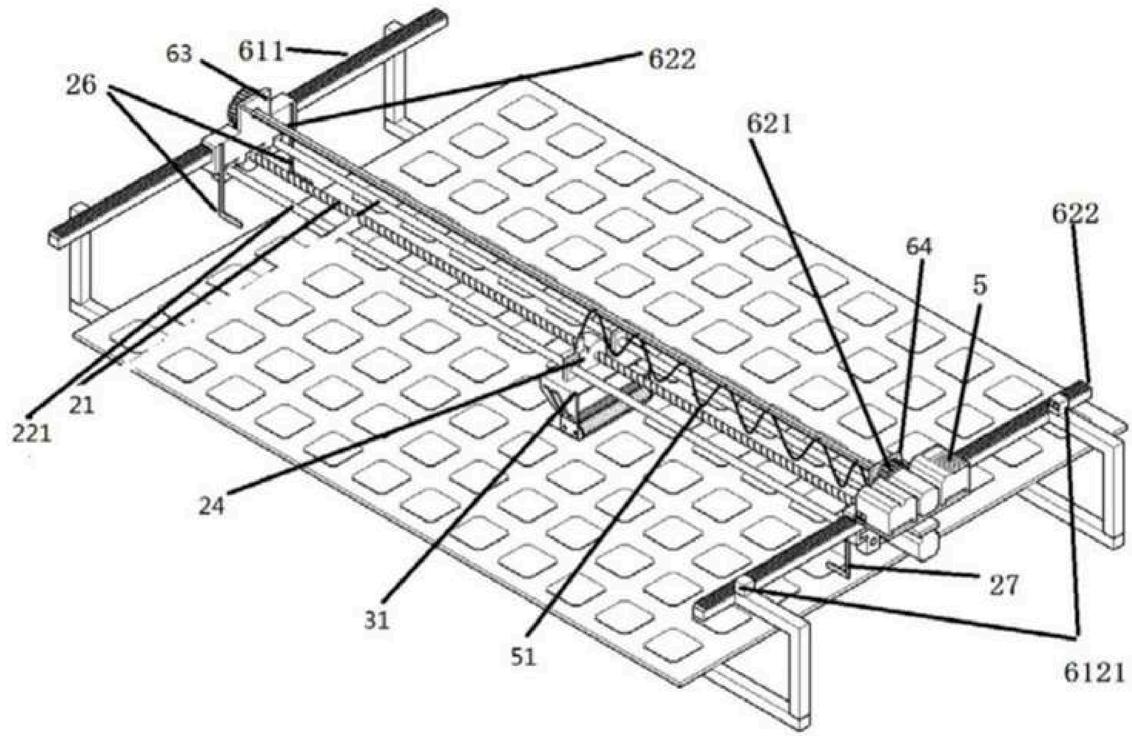


Figure 2-13: Patented Solar panel track cleaning device.

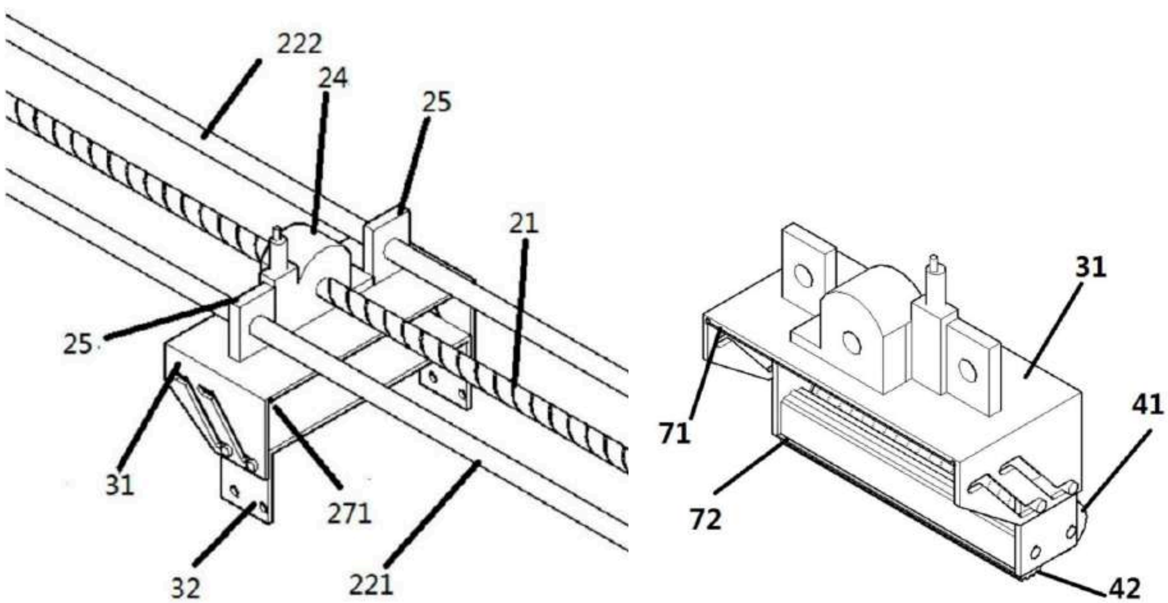


Figure 2-14: Patented lift-off mechanism that moves along a lead screw in longitudinal direction.

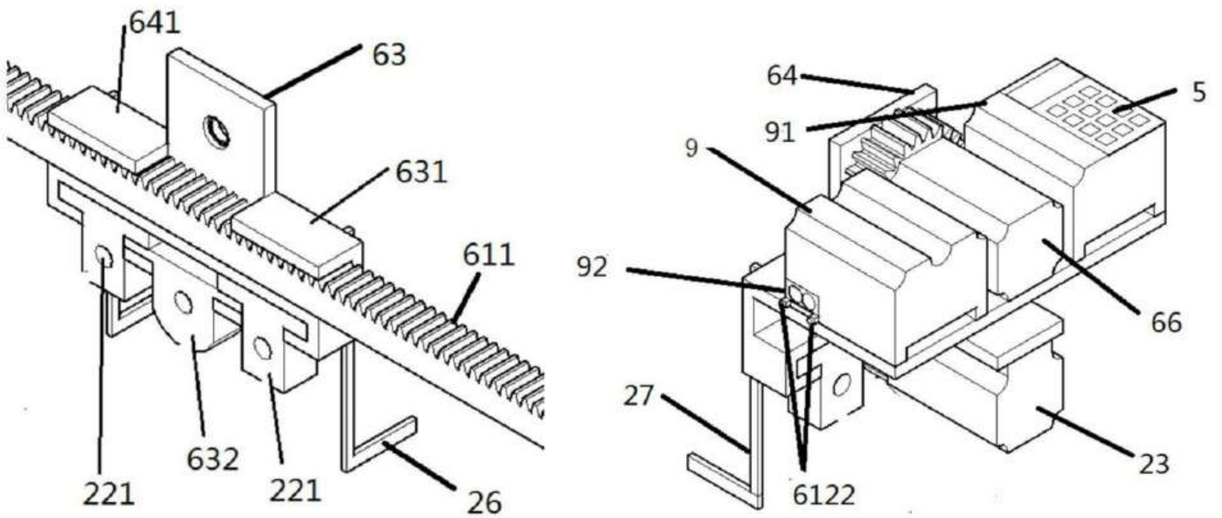


Figure 2-15: Lateral movement rack rail and gear system.

(The symbols in the figure are: screw 21, transmission DC motor 23, screw slider 24, balance bar slider group 25, fixed plate 31, movable plate 32, slide groove 311, slide column 321, first anti-slip portion 3111, second anti-slip portion 3112, first longitudinal limit strip 26, second longitudinal limit strip 27, first longitudinal limit sensor 261, second longitudinal limit sensor 271, controller 5, control line 51, first guide rail 611, second guide rail 612, upward gear 621, downward gear 622, first support plate 63, second support plate 64, transverse transmission shaft 65, transmission stepping motor 66, first balance guide wheel 631, second balance guide wheel 641, screw fixing member 632, transverse limit block 6121, lateral limit sensor 6122, brush 41, sponge 42, low-current brush 412, discharge brush 413, brush plate 4111, bristles 4112, roller brush motor 43, water storage chamber 421, first balance bar 221, second balance bar 222, cleaning effect inspection mechanism 7, ultraviolet lamp 71, ultraviolet intensity probe 72, non-return pawl 81, ratchet 82, electromagnet 83, reset spring 84, power supply mechanism 9, power storage module 91, wireless charging module 92, charging receiving end 921, charging radiating end 922.)

2.5 Examples of Existing Cleaning Devices:

- ❖ Various companies and researchers have developed both commercial and prototype solar panel cleaning systems, including:
- ❖ Ecoppia E4: A robotic cleaning system that works without water, using microfiber brushes and moving over panels with automated movement.
- ❖ Nomadd Desert Solar Cleaner: For arid environments, this robotic system efficiently removes dust without water usage.
- ❖ SolarCleano F1: A modular robotic cleaner featuring variable speed and brushes for different types of panels.
- ❖ SunPower's Self-Cleaning Glass: Inclusions of hydrophobic coatings that reduce dirt build-up and improve efficiency.
- ❖ Heliotex Automatic Cleaning System: Scheduled water and biodegradable detergent spraying for optimum cleaning.

2.6 Challenges and Future Directions:

- ★ Energy Consumption since some cleaning methods consume significant energy, reducing overall system efficiency.
- ★ Cost-Effectiveness also can be a problem since initial setup costs for robotic and electrostatic systems are high.
- ★ Environmental Sustainability since water scarcity and chemical degradation of coatings pose environmental concerns.
- ★ Smart Integration can also be a problem since AI-driven predictive maintenance and IoT-based monitoring systems are emerging trends for optimizing cleaning schedules (Wang et al., 2023).

2.7 Site Visit and Data Collection

Following the literature and background study, various solar panel installers and contractors within the local areas were consulted as to their common user base and their typical cleaning methods. The figure below showcases the site visit to survey Solar Panel commercial offices and manufacturers.

Figure 2-1: Site Visit Solar Panel Commercial Survey

Figure 2-2: Residential Rooftop Solar Panel Review

Figure 2-3: Commercial Solar Panel Flyer

Figure 2-4: Solar Panel Energy Factory Visit

Figures 2-1, 2-2, 2-3 and 2-4 illustrate the site visit for data collection from commercial and manufacturing sources regarding rooftop residential solar panels. To enrich the background study the following questions were asked:

- Solar Panel Dimensions and Specifications.
- Rooftop Solar Panel annual maintenance costs and requirements.
- Nominal user profile and market data
- Average annual expected performance drop in solar panel performance
- Recommended surface cleaning measures for rooftop solar panels
- Market possibility and scope for an automated cleaning device
- Possible product cost for an automated cleaning device

2.8 Research Mind Map

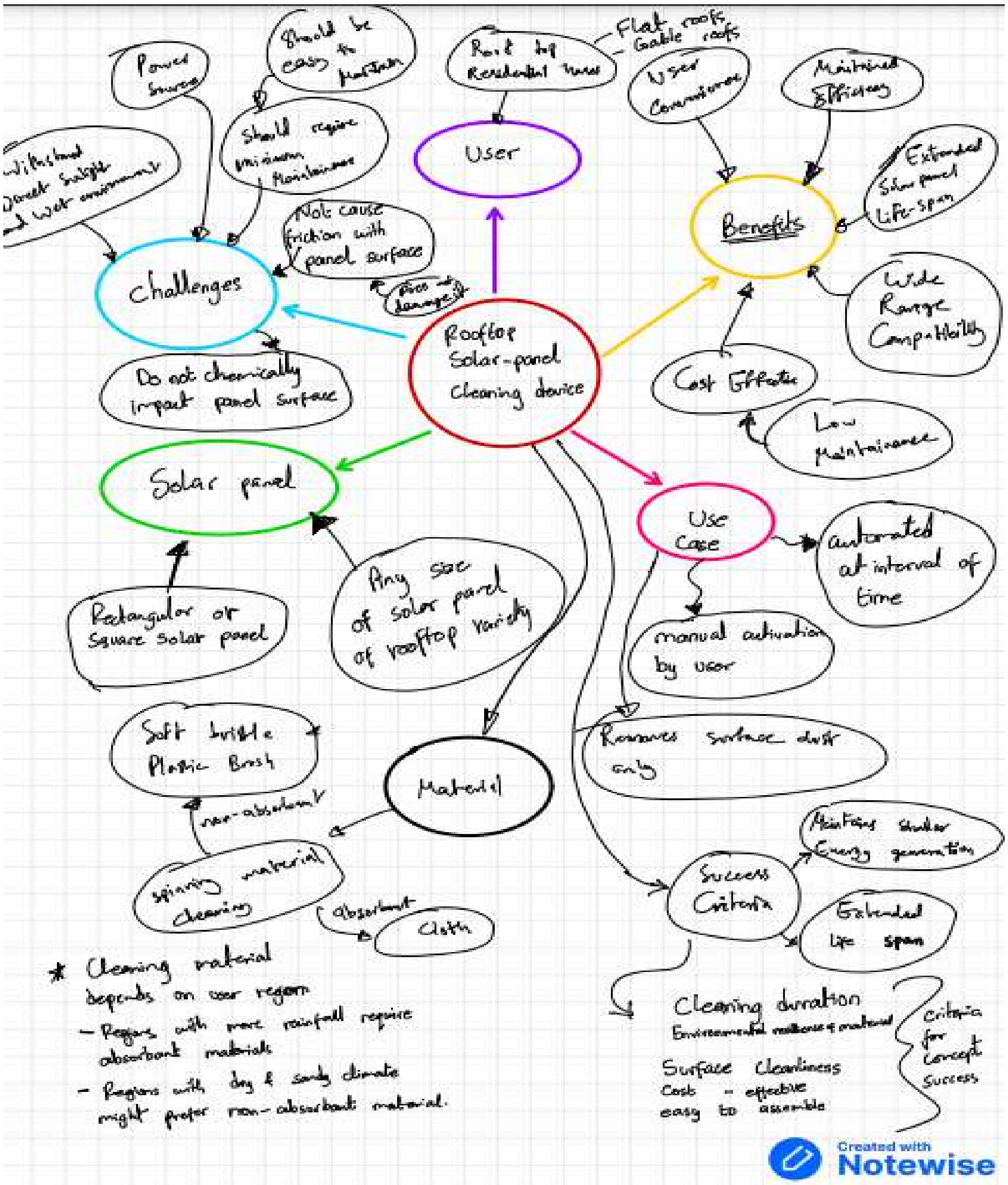


Figure 2-5: Mind Map Rooftop Solar Panel Cleaning Device

2.9 Product Design Specification

Combining the knowledge from the literature review and the mindmap, an aggregate of information can be cohesively integrated to produce a singular document that outlines the requirements of the device to be produced–Often referred to as the Product design specification (PDS). The following highlights the design brief and multiple criterias considered within the PDS.

Design Brief

The design focuses on producing a device capable of mounting along or upon rooftop solar panels, serving to clean the photovoltaic panel surface at automated intervals throughout its useful life. The device's priority is primarily to clean the photovoltaic surface of rooftop solar panels, which is subject to wear and tear in the form of dirt, debris. The solution would allow the panels to extend their life cycle, increase energy generation and improve upon their cost effectiveness. This device would be geared towards normal consumer households and residential building owners looking to optimize their energy generation. This device would be restricted to large-scale rooftop interlinked solar panels; Cleaning functionality is restricted to removing thin or fine layers of dust and cannot chemically interact with the photovoltaic layer.

Performance

Device must remove dust and debris effectively from the surface of the solar panel.

Uses soft bristle brush.

Follow an efficient cleaning path.

Cleaning round should not take more than 20 minutes.

Cleaning does not physically or chemically impact the surface of the panel or its performance.

Device motion should be smooth and error free (jitters and pauses due to excessive motor stress).

Minimal power consumption while idle.

The device can be controlled via smartphone application and a mounted control panel.

Device operates upon user command or according to a set time interval.

Notifies the user upon cleaning round completion or error occurrence.

<u>Quality & Reliability</u>

Durability

Stable and securely mounted to withstand wildlife tampering.

Reliability

High operating uptime (95% or more) is anticipated in typical applications, with consistent cleaning performance in a range of weather situations.

Insulation and Water Resistance

Electrical components are completely insulated to avoid short circuits or failures in wet weather, and they are waterproof or water-resistant.

Quality assurance

To guarantee the device's structural soundness and constant cleaning effectiveness, extensive testing is conducted against environmental variables (such as dust collection, mechanical wear), as well as drop tests.

Service Life

Made to last at least ten years under normal operating conditions, with only minor repairs or component replacements.

Market Limitations

Regulatory Compliance:

The device needs to adhere to industry requirements for electrical insulation, rooftop safety, and waste and water usage.

Competitive Landscape:

Must provide more ease and cleaning efficiency in order to compete with low-cost manual cleaning tools and current automation solutions.

Demand Seasonality:

Higher demand in locations with high rates of solar panel installation, particularly in places with high dust and pollen seasons (e.g., sunny climes with frequent dust storms or heavy pollution).

Channels of Distribution:

Distributable through solar panel merchants, internet marketplaces, and suppliers of energy solutions, it must be small and simple to ship worldwide.

Users

Main Client:

Owners of rooftop solar panels on residential and commercial buildings who want to maximize solar efficiency and reduce maintenance costs.

User Profile:

Businesses and environmentally aware individuals seeking sustainable ways to preserve solar efficiency.

Ease of Use:

Consumers want a low-maintenance, user-friendly gadget that functions well without requiring frequent manual intervention.

Automated or semi-automated device operation is suitable since it requires little setup and allows for safe rooftop operation.

Principal Advantages for Customers:

Increased energy output, fewer hand cleanings, and longer panel life spans because of routine maintenance.

The device must be able to adjust to various panel layouts and sizes.

Costs

Product Cost

Target pricing Point: A competitive pricing range that targets a larger spectrum of residential and commercial clients while striking a balance between affordability and feature-richness.

An estimated one-time payment price for the device would be around RM 5K.

Production Cost:

To maintain profitability while accounting for distribution, marketing, and service expenses, the total production cost should ideally stay between 30 and 40 percent of the selling price.

Maintenance Cost:

Customers should have to pay little for the device's upkeep; wear-prone elements should be simple to swap out for less expensive ones.

Total Cost of Ownership:

Reduced by including self-cleaning capabilities and long-lasting, weather-resistant materials to increase operational longevity and lower user-related long-term costs.

Weight

The weight of the device must be low enough that it does not put any strain on the solar panel mounts or the roof.

Aim to keep the device below 10kg to install it independently without adding additional load on the solar panel, structure and roof.

Focus on keeping a balanced weight but make sure it is durable and stable enough that it can’t be moved or thrown away by the wind or weather.

Patents

CN112058842B: Solar panel cleaning device

CN210273955U: Solar cell panel cleaning device

CN220401694U: Solar cell panel cleaning device

KR102373790B1: Cleaning machine and cleaning system of solar cell panel

CN108405383B: Solar cell panel has rail cleaning device

EP2529162B1: Intelligent & self-cleaning solar panels

CN221806887U: Solar panel cleaning device

CN113042409A: Solar panel maintenance device

Packaging

Materials used for packing must be sustainable and recyclable, as much as possible.

Make sure sensitive electronic and mechanical components are safe during shipment with cushioning and secure compartments.

Add labels for unpacking and installation to avoid damaging on receipt.

Safety

The device shall conform to safety requirements for electronic and mechanical devices with outdoor interactive environments.

Implement protective measures to prevent performing in mode during servicing. The product manual should have safety warnings regarding electric components, mechanical components, water usage and cleaning protocols.

Legal:

The device should not violate relevant environmental and safety legislation with regard to local and international law concerning the automated cleaning technology.

The design should not harm the environment by following regulatory standards when it comes to the e-components used, the amount of water consumed, and the chemicals used in cleaning.

When there is patented technology to be utilized, the rights of intellectual property should be considered.

Size:

The cleaning device should be compact enough to operate on standard solar panel sizes and move across various panel layouts.

The width and length of the device are to fit standard panels, while tuning is also to be provided for different panel settings.

Testing:

Rigorous testing for durability in various weather conditions (heat, rain, and dust) is required to ensure performance over time.

Conduct safety testing to verify the device's stability, effectiveness, and non-damaging operation on the panel surface.

Performance testing should measure cleaning efficiency, cycle time, and water/electricity usage.

Documentation

Concise User Guide

Develop a simplified guide covering essential setup, operation, and maintenance steps to assist users with quick understanding.

Basic Technical Support Notes:

Include clear assembly instructions and a list of primary parts with brief explanations, aimed at assisting students or instructors in troubleshooting.

Digital Supplement:

Provide a QR code linking to digital resources, such as quick setup videos or a PDF version of the manual, for easy access on mobile devices.

Safety and Operation Warnings:

Clearly list necessary safety precautions regarding water, electrical, and mechanical components to ensure safe usage within the classroom or demonstration environment.

Materials

Cost-Effective, Lightweight Materials:

Select materials like aluminum or durable plastics to minimize costs and weight, suitable for a short-term project.

Weather-Resistant Coatings:

Apply basic protective coatings to prevent minor corrosion if used outdoors, while keeping the device budget-friendly.

Readily Available Parts:

Use commonly available, low-cost components for assembly to ensure the device is accessible for student projects.

Non-Toxic and Recyclable:

Prioritize non-toxic, recyclable materials to minimize environmental impact and align with sustainable project guidelines.

Product Life Span

Sustainable Disposal:

Ensure that primary materials are recyclable or easy to dispose of, simplifying the end-of-life process for a student project.

Maintenance:

Device should only require maintenance in response to external factors; otherwise it is expected to work reliably throughout its life in service.

Device must be designed for ease of maintenance and maximum reliability.

Aesthetics:

Device should look robust and well-made. Shows branding labels on any provided exterior space.

Colors can be matched with clients specification if required or a neutron tone of colors can be selected for “general” appearance.

Environment:

Capable of withstanding heavy rain and direct sunlight without hindrance in functionality.

Non-lightning-inducing exterior.

Mounts on the solar panel’s frame or mounting rails.

3.0 Concept Generation and Selection

3.1 Function Decomposition

With the PDS requirements to form the basis of the design, concepts must be generated and evaluated to proceed further. To begin formulating concepts and selecting components, it is necessary to break down the processes involved within this solar panel cleaning device from beginning to end. The figure below illustrates a highly-detailed function decomposition for the device, with its expected inputs and outputs outlined.

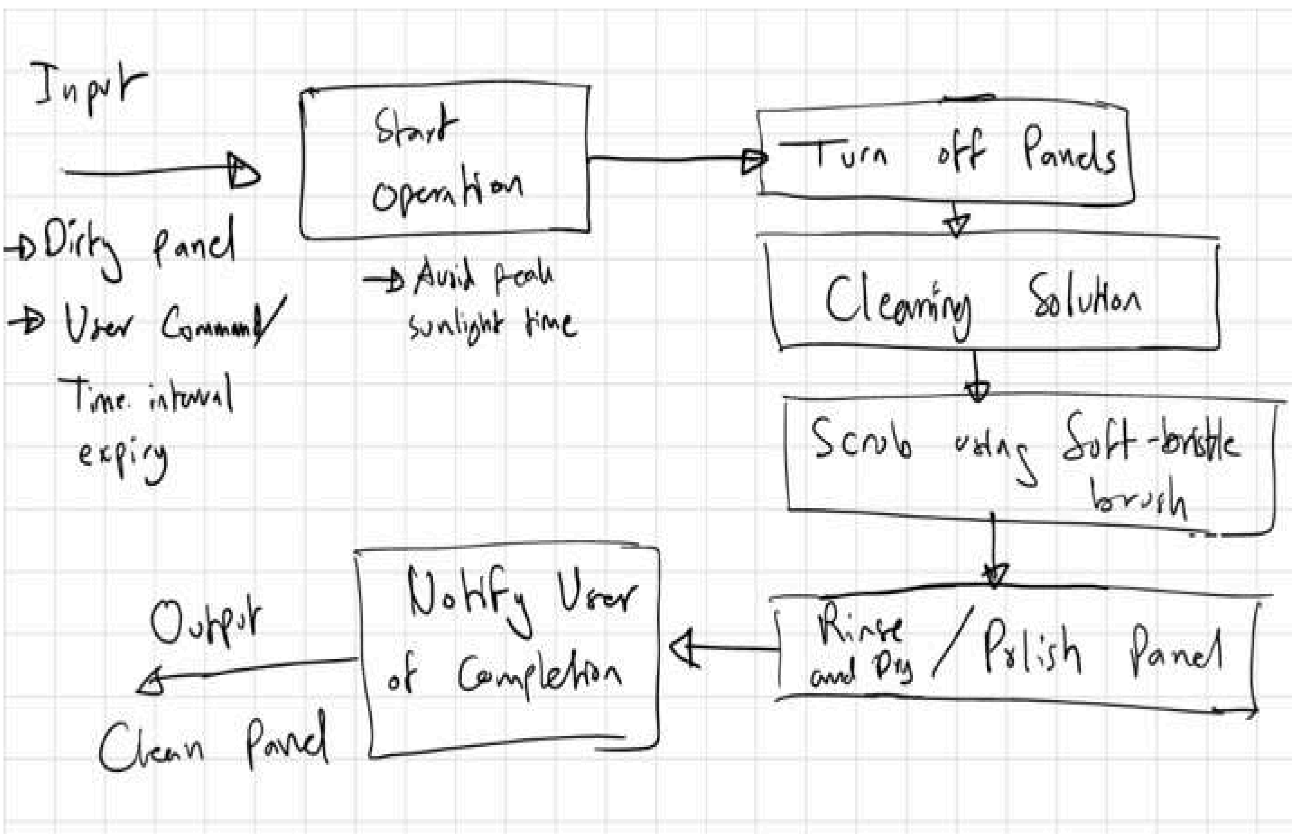


Figure 3-1: Function Decomposition

As shown above, the function decomposition begins with an input of a dirty solar panel, and an expected time interval that has since expired, triggering the cleaning mechanism of the device. Hence, the operation begins, avoiding peak sunlight hours to prevent energy generation from being interrupted. The first step is to turn off the panels, followed by an application of cleaning solution if required, scrubbing, rinsing-polishing and finally notifying the user of the cleaning status by completing the process.

3.2 Morphological Chart

The functions outlined in the previous section are then used as criterias to select custom components for each key operation, allowing the formation of a rudimentary concept.

Function/Option	1	2	3	4	5
Mounting	Suspended by bracket rod	On Solar Panel	On solar panel mounting railings	Magnetic Clamp	Neodymium magnetic chain around solar panel frame
Moving across panel	wheels inside the device	Motorized Rollers on both sides	Robotic Arm	Motorized Pulley-Belt System	Rollers on one side
Cleaning Solution	Ammonia Free Glass Cleaners	Isopropyl Alcohol	Water-based Detergent	No Solution	Deionised water
Scrubbing Panel	Foam Sponge	Silicon Squeeges	Spinning soft brush	Rolling soft brush	Vertical spin brushes
Rinsing & Drying / Polishing	Air Hose	Viper Blade	Air Blade drying	Pressurized air	Water Sprinkler/Steam for drying
Notifying user	Smartphone App	Cues on control panel	Integration with Smart Home system	Analogue Alarm System for progress	

Figure 3-2: Morphological Chart

The figure above illustrates a morphological chart that represents each key function with its appropriate possible options in a matrix. To generate a concept, one option from each category is selected, the choices are then combined into an “idea”.

3.3 Concept Generation

Hence, following figure 3-3, eighteen individual concepts (three per group member) were generated and sketched with the creator referenced in the following figures:

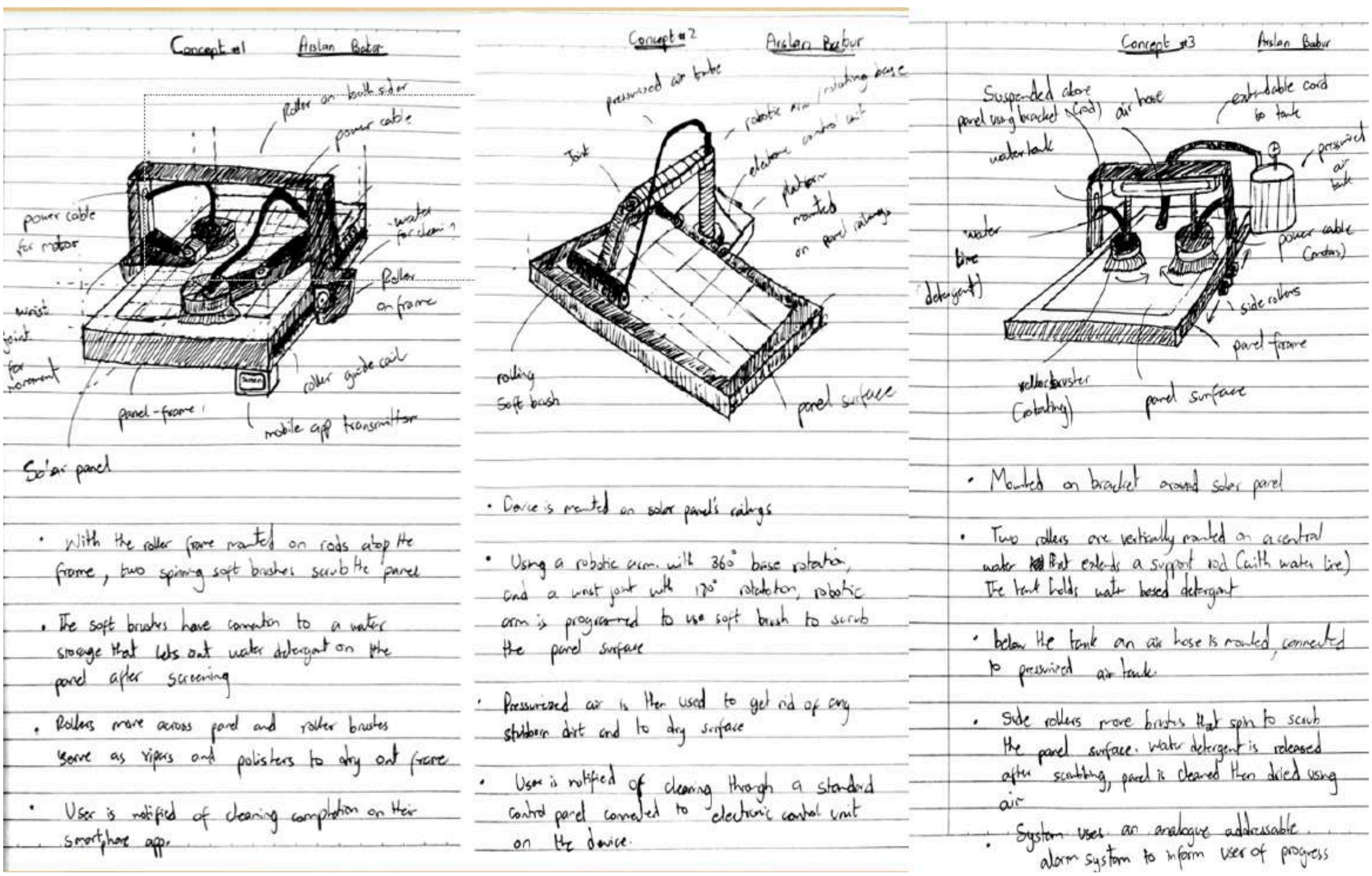


Figure 3-3: Concept Generation. Concept 1, Concept 2 and Concept 3 (Arslan)

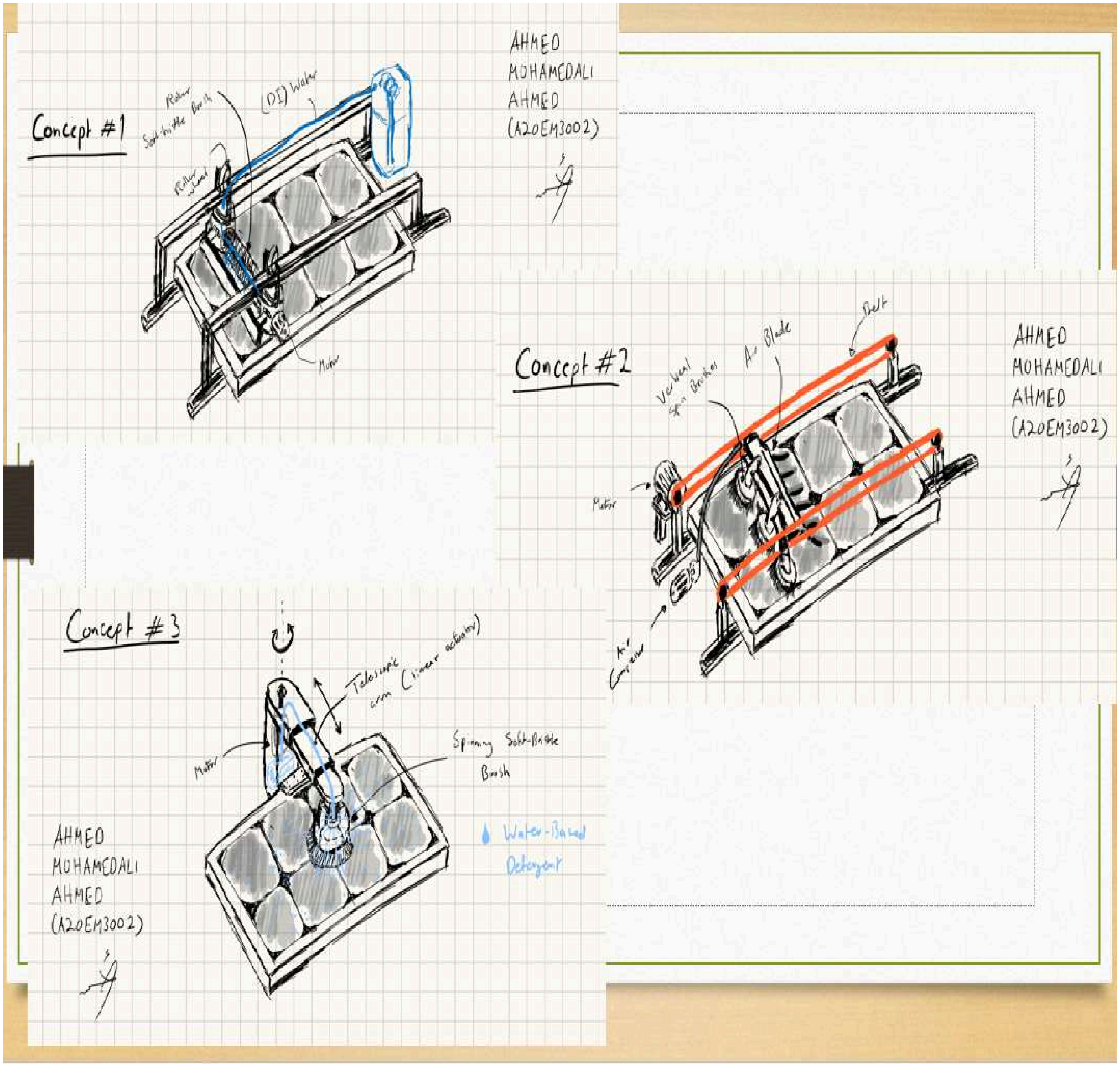


Figure 3-4: Concept Generation. Concept 4, Concept 5, Concept 6 (Ahmed)

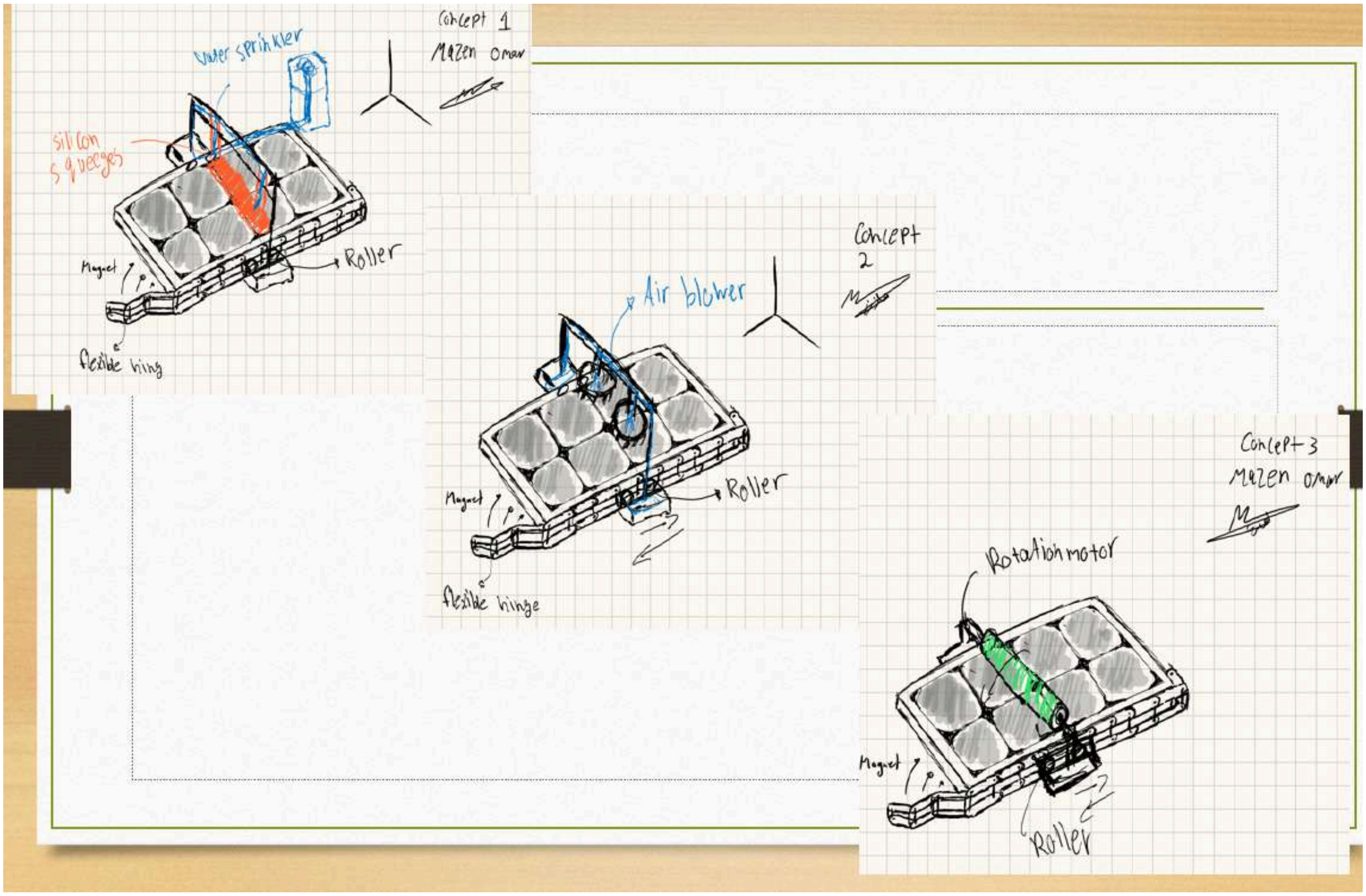


Figure 3-5: Concept Generation. Concept 7, Concept 8, Concept 9 (Mazen)

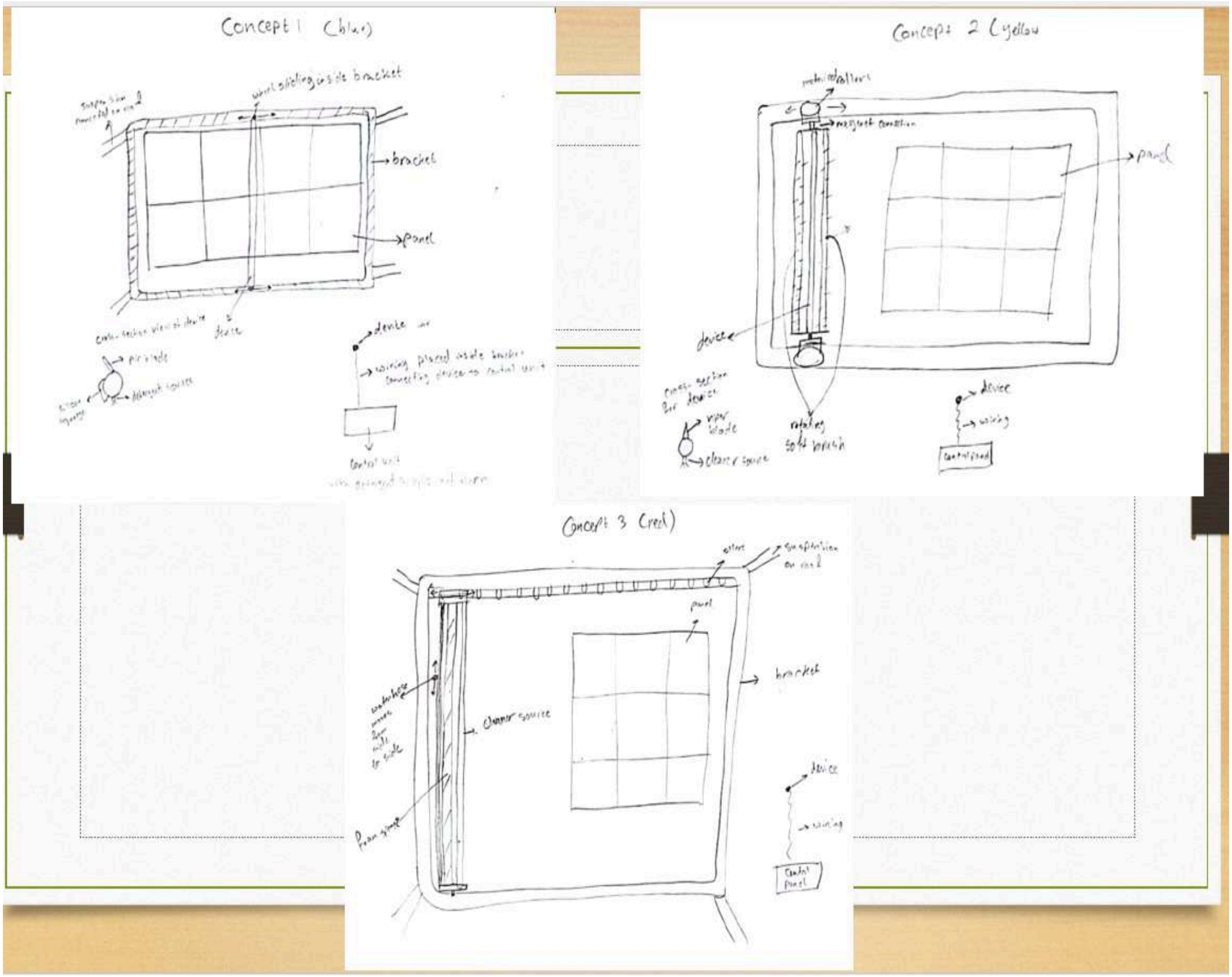


Figure 3-6: Concept Generation. Concept 10, Concept 11, Concept 12 (Moaz)

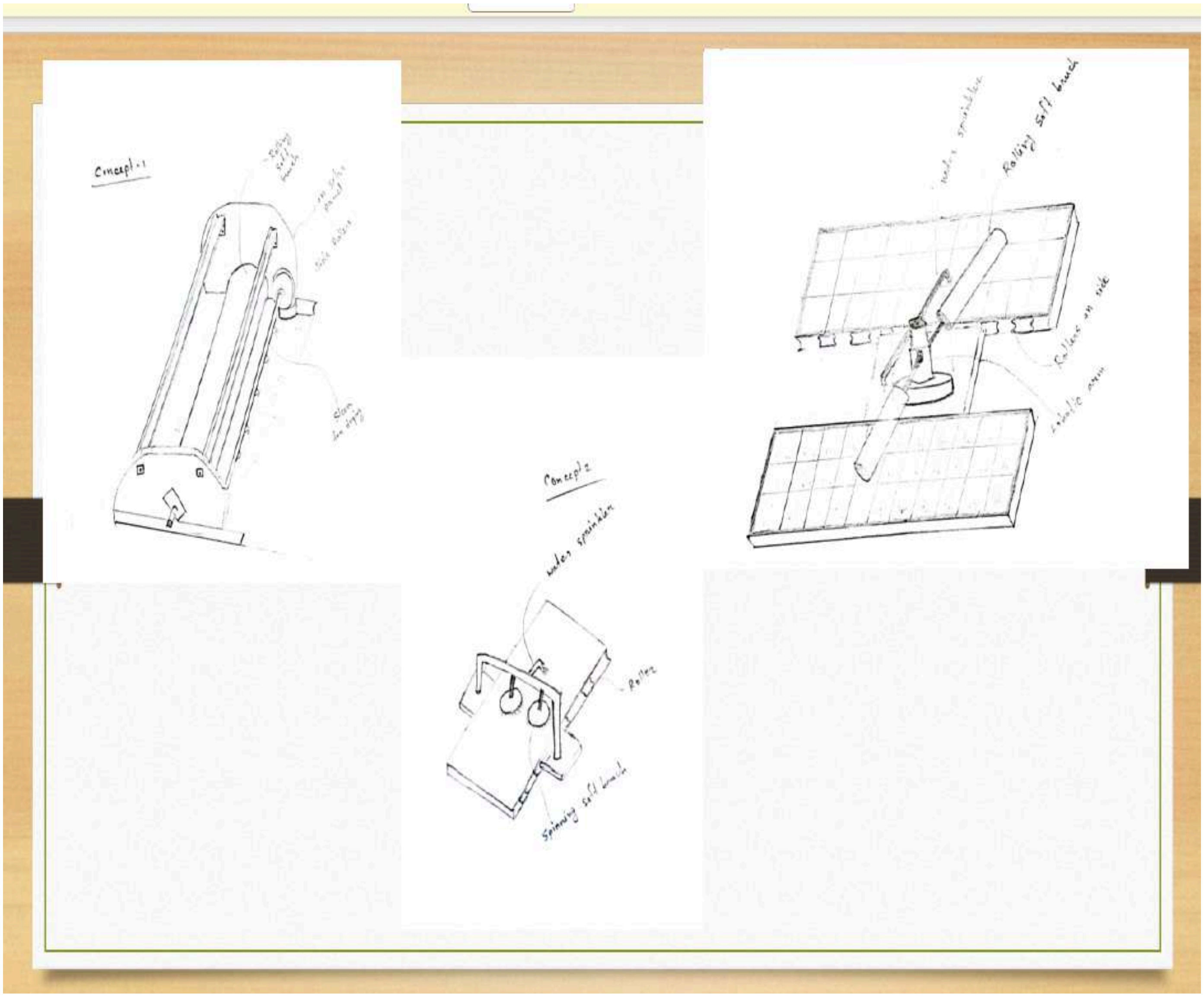


Figure 3-7: Concept Generation. Concept 13, Concept 14, Concept 15 (Taraq)

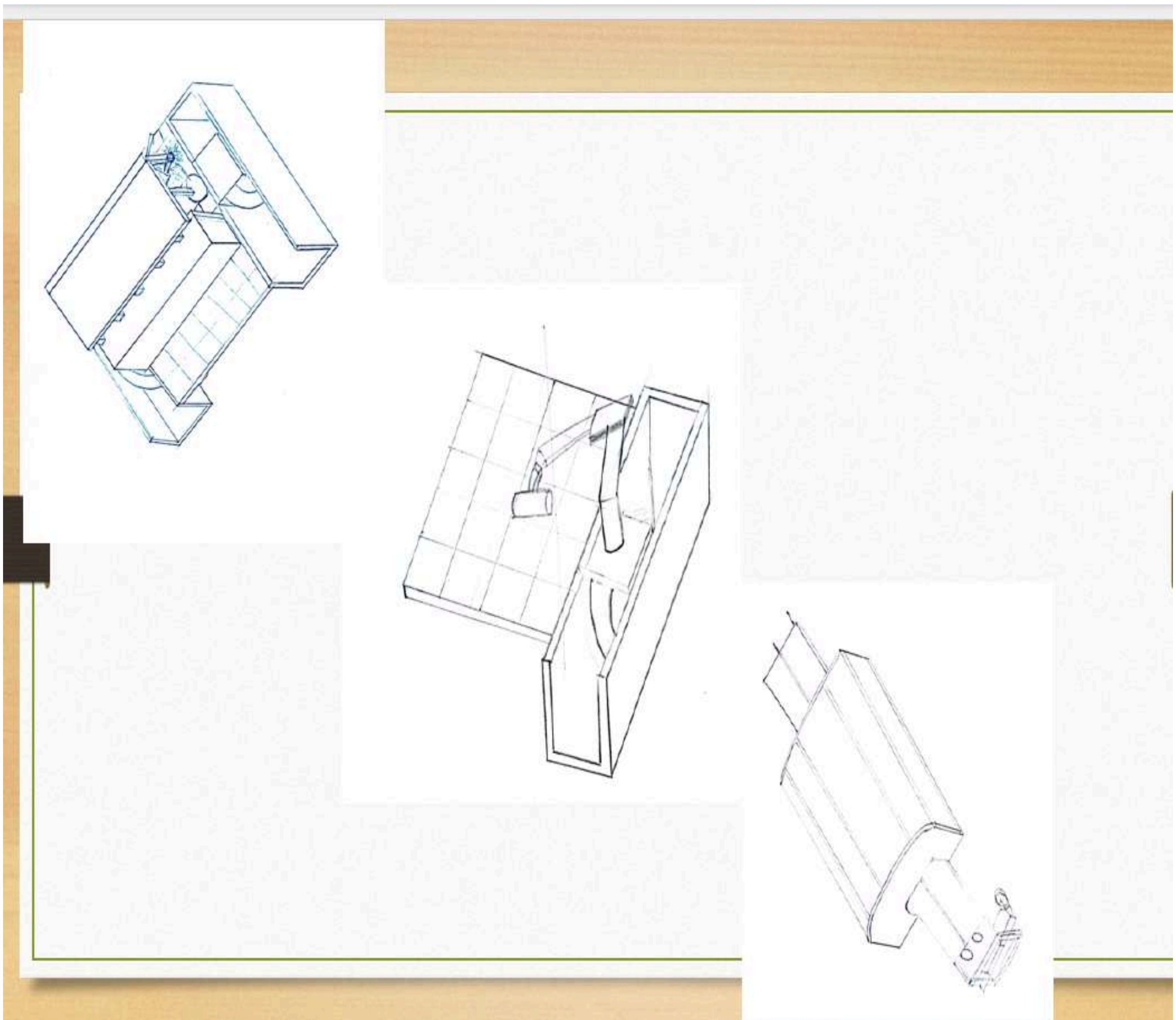


Figure 3-8: Concept Generation. Concept 16, Concept 17, Concept 18 (Shamim)

3.4 Concept Evaluation and Brainstorming

Table 3-1: Concept Selection 1

CRITERIA	Weightage (5)	CONCEPT SELECTION -1																	
		Arslan -1	Arslan -2	Arslan -3	Mazen-1	Mazen-2	Mazen-3	Ahmed-1	Ahmed-2	Ahmed-3	Moaz-1	Moaz-2	Moaz-3	Shamim-1	Shamim-2	Shamim-3	Taraq-1	Taraq-2	Taraq-3
Able to Scrub	5	3	4	4	3	4	5	5	4	3	3	4	3	4	3	4	3	3	3
Able to Clean with Solution	5	4	4	2	4	2	1	4	2	4	4	1	4	4	4	4	2	4	4
Able to Dry/Polish	5	3	3	4	4	4	5	4	4	3	4	4	4	4	3	3	3	3	3
Able to Notify User	5	4	4	5	2	2	2	2	2	2	4	4	2	2	2	2	2	2	2
Ease of Manufacturing	3	3	4	2	3	3	3	4	3	4	3	3	4	3	3	3	3	3	3
Ease of Assembly	3	3	4	3	4	3	4	4	4	4	3	3	3	3	3	3	3	3	2
Cost Effectiveness	3	2	3	2	4	4	4	3	3	3	3	3	4	3	3	3	3	3	2
Cleaning Duration	3	4	3	4	3	4	4	4	4	3	3	3	4	4	3	4	4	3	3
Environmental Resilience	4	3	4	4	4	4	4	3	3	4	3	3	4	4	4	4	4	4	4
Sustainable Material	3	3	2	3	4	4	4	3	4	3	4	3	4	4	4	3	4	3	3
Aesthetics	3	2	3	2	3	3	3	3	3	3	3	2	3	2	2	3	3	2	2
Reliability	4	4	3	3	3	4	4	4	4	3	3	3	4	4	4	3	4	3	3
Safety	4	4	4	4	4	4	4	3	3	4	3	4	3	5	4	4	4	4	3
Total Score (Sum of Weightage x Score)	/	165	176	167	172	171	179	178	163	164	168	156	175	179	162	166	158	155	145

Once the concepts were generated, each concept was evaluated using a specific criteria along with a weightage. The concepts with the highest scores were carried over to the next stages for further brainstorming and development. The first round of evaluation can be seen as tabulated in table 3-1.

The selection criteria for the components is elaborated on as follows:

- **Able to Scrub** : The measure of capability of the device to scrub a surface.
- **Cleaning with Solution**: The ability of the device to integrate a cleaning solution.
- **Dry/Polish** : The ability of the device to dry or polish a surface.
- **Notify User**: The ability of the device to notify its users of cleaning status.
- **Ease of Manufacturing**: The ease with which the device can be manufactured.
- **Ease of Assembly:** The ease with which the device can be assembled.
- **Cost Effectiveness**: Relative effectiveness as compared to cost.
- **Cleaning Duration**: How fast can the device complete two cleaning cycles.
- **Environmental Resilience**: Resistance to the environment. (Rain etc.)
- **Sustainable Material**: How easy it is to source and dispose of the base materials
- **Aesthetics**: Appearance of the device.
- **Reliability**: Ability to reliably function.
- **Safety**: Overall safety threshold to prevent injury or accident.

As discussed previously, each selection criteria was given an accurate weightage score out of (5) representing its importance. The higher the score, the more essential the criteria to the success of the device. Hence, it can be noted that the highest rated concept generation in the first round was found to be the concept labelled (Shamim-1) with an overall rating of 179. This concept was then set as the DATUM for the 2nd round of evaluation and the seventeen remaining concepts were improved upon through group discourse and discussion, which lead to adding further explanation, suggestion of specific material use or small redesign of mechanism.

The brainstorming discourse is as illustrated in the figure below:

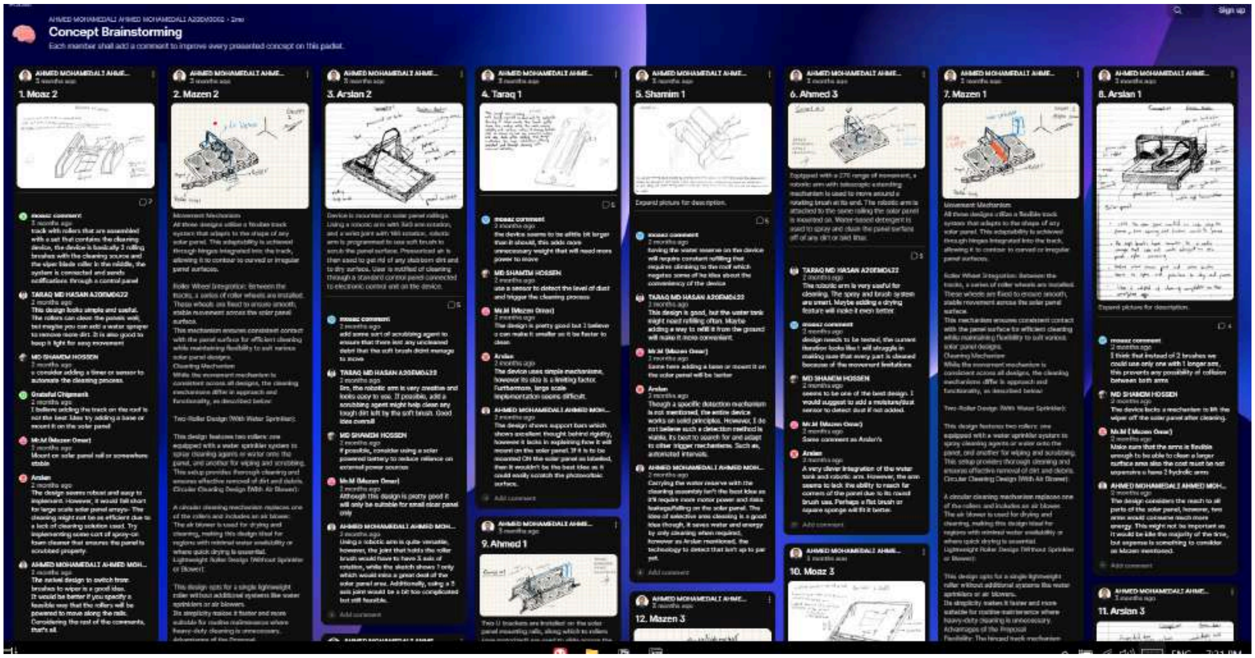


Figure 3-9: Padlet Brainstorming for Concept Redesign and Reiteration

It is noted that for further review, the padlet link of the brainstorming discussion is provided within the appendix section of this document. As illustrated above, each concept was evaluated by the other members, until all seventeen concepts had been commented on and reworked. Hence, these new concepts were judged against the selected DATUM to determine the final concept to be selected.

Table 3-2: Concept Selection 2

CRITERIA	Weightage (5)	CONCEPT SELECTION -2																	
		Shamim-1	Arslan -1	Arslan -2	Arslan -3	Mazen -1	Mazen-2	Mazen-3	Ahmed-1	Ahmed-2	Ahmed-3	Moaz-1	Moaz-2	Moaz-3	Shamim-2	Shamim -3	Taraq-1	Taraq-2	Taraq-3
Able to Scrub	5		-1	1	-1	-1	-1	0	1	-1	-1	-1	0	-1	-1	1	-1	-1	-1
Able to Clean with Solution	5		0	0	0	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0
Able to Dry/Polish	5		-1	-1	-1	0	1	1	0	1	1	0	0	1	1	1	1	-1	1
Able to Notify User	5		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ease of Manufacturing	3		0	1	0	1	0	1	1	0	1	1	0	-1	1	0	0	0	0
Ease of Assembly	3		0	1	0	1	1	1	1	0	0	1	1	1	1	-1	1	1	0
Cost Effectiveness	3	DATUM	-1	-1	-1	-1	-1	0	1	-1	-1	-1	0	0	-1	-1	-1	0	-1
Cleaning Duration	3		-1	-1	0	-1	0	0	0	0	-1	-1	0	0	-1	-1	0	0	0
Environmental Resilience	4		1	1	0	0	0	0	0	0	0	0	0	0	0	-1	-1	0	-1
Sustainable Material	3		1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Aesthetics	3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Reliability	4		-1	-1	0	0	0	0	-1	0	-1	0	0	-1	-1	-1	0	0	0
Safety	4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Score (Sum of Weightage x Score)	/		-8	8	-5	0	0	11	15	2	-2	3	8	1	1	-2	1	-2	-2

Table 3-2 represents the data for the second round of concept evaluation. However, unlike the first round, in this table each concept is only compared to the DATUM and scored for being better than (+1), the same as (0) or worse than (-1) in every single selection criteria. It is noted that the selection criteria remain the same for both rounds of evaluation.

Hence, it can be noted that the highest scoring concept was found to be concept labelled Ahmed-1. The following figure illustrates the updated concept that was selected to be the final one.

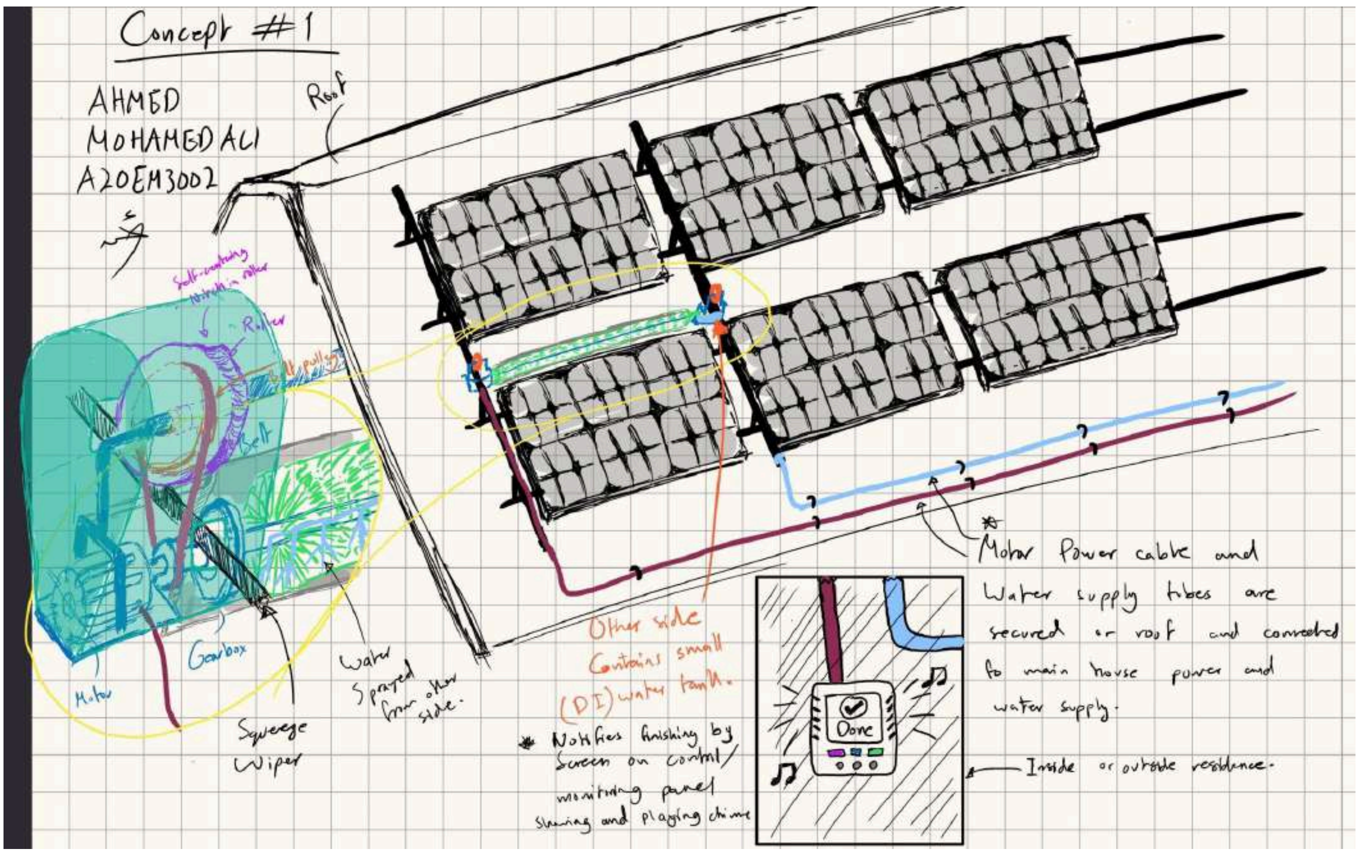


Figure 3-10: Final Concept Revised Sketch

As shown in the figure above, the concept utilizes a long rotating brush that covers the width of the panel. The brush itself is motorized, with a gear train that utilizes rollers mounted on rooftop railings. The gear train transfers the rotational motion into translational motion of the device. Hence, the motorized roller is used to scrub the photovoltaic surface as the entire rig goes across the length of the panel.

3.5 Final Concept Selection

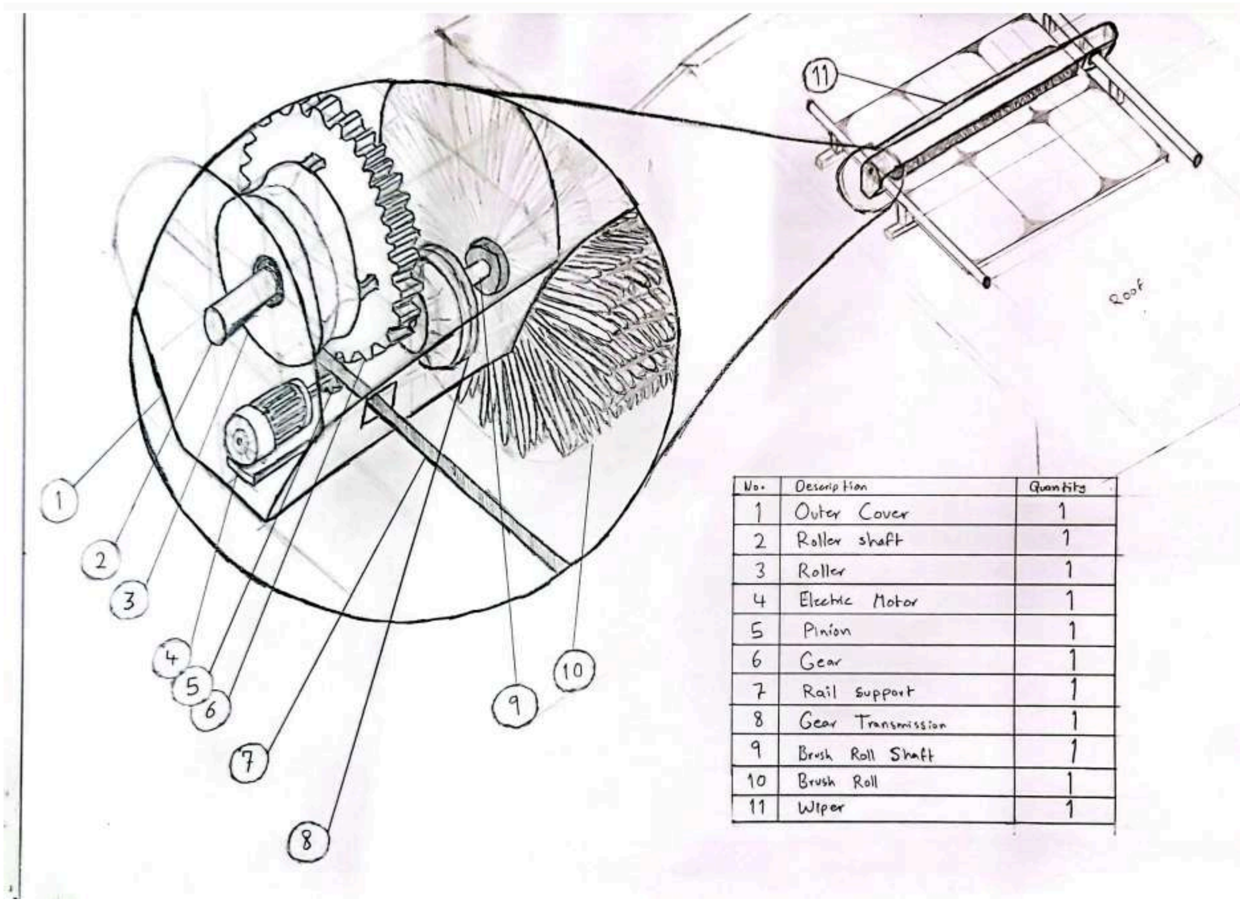


Figure 3-11: Detail Final Concept Sketch

The figure above shows an initial detailed section final concept sketch for one side of the rooftop cleaning device. Following the PDS requirements, a design that minimizes costs and efficiently utilizes the gear train to transfer power was implemented. Furthermore, the gear train was designed with only one motor in mind. Hence, the rotational motion of the motor was translated to the translational railing motion using gear meshing. The detailed gear tear drain will be explored within the embodiment stage.

Overall, the sketch above was used as an initial base-design. More details were then added until the concept was fully realized.

4.0 Detail Embodiment

This design stage focuses on implementing details within the conceptual design stage to allow for better planning later on.

4.1 Initial Embodiment Design

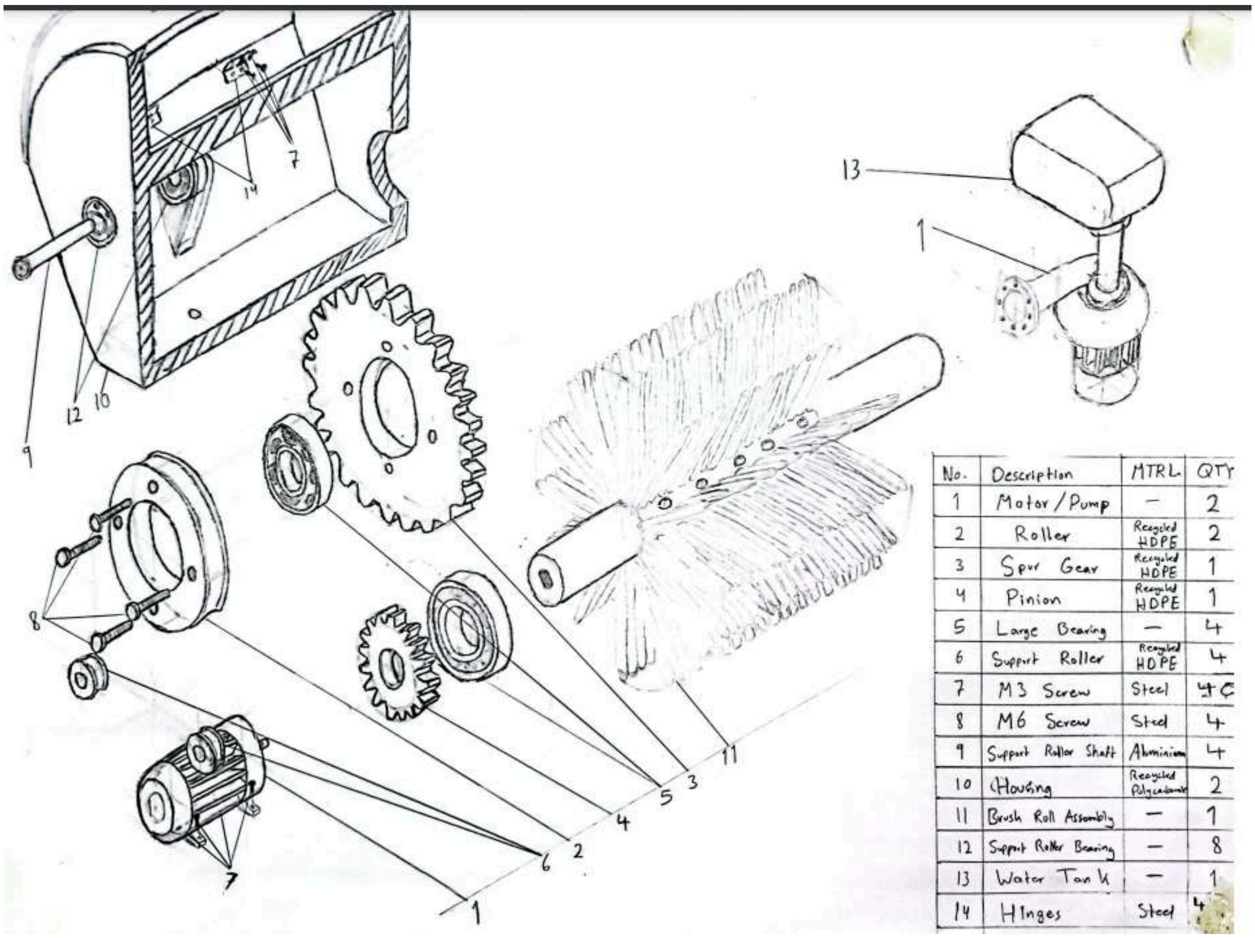


Figure 4-1: Exploded View Sketch

The initial embodiment design serves as an initial foothold for further development. Hence, the figure above illustrates a rudimentary exploded view sketch of one side of the device. It is noted that the motor mechanism is simply replicated on the end of the broom, but instead of a pinion, it utilizes a follower gear.

With an initial understanding of the design, it is necessary to assign materials for each component with relevant justifications. Table 4-1 outlines each key component with its chosen material and a reason that highlights its need.

Table 4-1: Material Selection for Components

No.	Component	Material	Justification
1	Roller	Recycled HDPE (High Density Polyethylene)	HDPE is very wear resistant and can withstand different corrosive materials and weather conditions. Rollers will be subject to stress as it will be holding the weight of the device while moving. Recycled for sustainability. Not metal for weight efficiency.
2	Motor	Null (outsourced)	-
3	Spur Gear	Recycled HDPE (High Density Polyethylene)	Same reason as Roller
4	Pinion	Recycled HDPE (High Density Polyethylene)	Same reason as Roller
5	Brush Roll	Recycled Nylon	It is most commonly used for soft bristle brushes as it ensures no scratches on the solar panel. Using recycled nylon for sustainability and for its known wear resistance, strength and cleaning effectiveness.
6	Railings	Aluminium	Strength, Rigidity, availability
7	Support Railings	Aluminium	Strength, Rigidity, availability
8	Outer Cover	Polycarbonate	Lightweight, Cost-Effective and Recycable
9	Water Tank	Outsourced	-
10	Water Pump	Outsourced	-
11	Wiper	Outsourced (Repurposed Squeegies)	-
12	Chassis	Aluminium	Lightweight, cheap and strong enough.
13	Bearings	Outsourced	-
14	Bolts & Nut / Screws	Outsourced	-
15	Brush Roll shaft	Recycled PVC	Availability, Resistance to rust compared to metal pipes, lightweight (less load on motor while rotating)
16	Gear Transmission	3D printed (PET-G filament)	Cheaper and better availability compared to Nylon. 3D printed for custom transmission.

4.2 Bill of Material (BOM)

The following table tabulates the data for the bill of materials following the initial embodiment design. The BOM (bill of materials) summarizes the quantity for each component, and calculates the total number of components involved. As can be seen in the table below, the initial design holds 78 components.

Table 4-2: Old BOM (Pre-DFMA)

No.	Description	Material	QTY
1	Motor/Pump	-	2
2	Motor/Pump	Recycled HDPE	2
3	Spur gear	Recycled HDPE	1
4	Pinion	Recycled HDPE	1
5	Large bearing	-	4
6	Support roller	Recycled HDPE	4
7	M3 screw	Steel	40
8	M6 screw	Steel	4
9	Support roller shaft	Aluminium	4
10	Housing	Recycled polyca	2
11	Brush Roll assembly	-	1
12	Support roller bearing	-	8
13	water tank	-	1
14	Hinges	Steel	4
Total			78

4.2 Design Efficiency and DFMA

Following the initial design, the number of components in the BOM is taken into account as the design goes through a rework using the DFMA (Design for Manufacturing and Assembly) strategies. This strategy revolves around reducing the total number of parts by combining redundant parts into one, and by utilizing a base/housing that holds all the parts, thereby simplifying the assembly process.

Table 4-3: DFMA Part Reduction

Sub-Assembly	No.	Part List (BOM)	QTY.	Part Reduced	QTY.	Modified Part List (BOM)	QTY.
Movement Compartment (Left)	1	Motor	1	Spur Gear	1	Motor	1
	2	Pinion	1	Track Roller	1	Pinion	1
	3	Large Bearing	2	Hinges	2	Large Bearing	2
	4	Spur Gear	1	M3 Screws	8	Track Roller Gear	1
	5	Track Roller	1	M6 Screws	4	Small Bearing	2
	6	Support Track Roller	2	Small Bearing	2	Housing	1
	7	Small Bearing	4			Support Track Roller	2
	8	Housing	1				
	9	Hinges	2				
	10	M6 Screws	4				
	11	M3 Screws	8				
		Total	**27**		**18**		**10**
Water Dispensing Following Compartment (Right)	1	Pump	1	Spur Gear	1	Pump	1
	2	Pinion	1	Track Roller	1	Pinion	1
	3	Large Bearing	2	Hinges	2	Large Bearing	2
	4	Spur Gear	1	M3 Screws	8	Track Roller Gear	1
	5	Track Roller	1	M6 Screws	4	Small Bearing	2
	6	Support Track Roller	2	Small Bearing	2	Housing	1
	7	Small Bearing	4			Pipe Fittings	1
	8	Housing	1			Swivel Fitting	1
	9	Hinges	2			Tank	1
	10	Tank	1			Support Track Roller	2
	11	Pipe Fittings	1				
	12	Pipe	1				
	13	Swivel Fitting	1				
	14	M6 Screws	4				

	15	M3 Screws	8				
		Total	**31**		**18**		**13**
Effective Cleaning Connectors	1	Roller Brush Shaft	1			Roller Brush Shaft	1
	2	Wiper	1			Wiper	1
	3	Shield	1			Shield	1
		Total	**3**		**0**		**3**

The table above tabulates how each sub-assembly was broken down to its part list. The parts were then reduced, with a new modified part list specified in the table. As mentioned, the objective of the DFMA analysis is to ensure the most efficient design by reducing the number of redundant components.

It can be noted that movement sub-assembly had 18 components reduced, similarly the water movement compartment also had 18 parts reduced. Lastly, the cleaning connectors had no parts reduced.

4.3 New Bill of Material (BOM)

Table 4-4: New BOM (Post DFMA)

No.	Description	Material	QTY
1	Motor/Pump	-	2
2	Motor/Pump	Recycled HDPE	2
3	Spur gear	Recycled HDPE	0
4	Pinion	Recycled HDPE	1
5	Large bearing	-	4
6	Support roller	Recycled HDPE	2
7	M3 screw	Steel	32
8	M6 screw	Steel	0
9	Support roller shaft	Aluminium	4
10	Housing	Recycled polyca	2
11	Brush Roll assembly	-	1
12	Support roller bearing	-	6
13	water tank	-	1
14	Hinges	Steel	0
Total			57

The table above tabulates the new BOM (Bill of Materials) after DFMA has taken place. It is noted that after part reduction, the total number of parts is reduced to (57) from an initial (78), leading to a total of (21) redundant parts being removed or combined with other parts.

4.4 Failure Mode Effect Analysis (FMEA)

Table 4-5: Failure Mode Effect Analysis

Sub Assembly	Potential Failure Effect	Potential Cause of Failure	Severity	Occurence	Detection	RPN	Action	Person in Charge
Movement	Loss of traction of track roller wheels.	1) Wet or dirty railing at roof angle. 2) Worn down roller. 3) Exessive torque to roller causing slippage.	8	7	8	448	1) Ensure grip material on roller surface. 2) Adopt worm gear design.	ahmed
	Motor vibration and insecure to housing.	Motor and assembling screws in contact with the plastic housing cause it to worn out over time; hence loose screws causing unstable motor and damaged housing.	9	7	5	315	1) Add metal plate on motor mounting bay. 2) Install metal screw hole inserts to minimize metal to plastic contact effect.	moaaz
	Failure of motor power transfer	1) Gear mesh misalignment. 2) Worn out gears 3) Loose or Worn out shaft key slot connecting motor. 4) Gear Train is not efficient.	9	5	9	405	1) Conduct gear tooth fatigue analysis to determine the maximum amount of power transmission possible. 2) Ensure lock-reinforcing bearing slot design. 3) Exaggerate shaft key slot shape to minimize chance of slipping. 4) Optimize gear train design to use more space efficient and be more stable.	arslan
	Rollers unstable or going completely off the railings.	1) Exessive torque to rollers. 2) Poor roller design. 3) Dirt/Obstacle on railing.	10	7	9	630	1) Add one more gear reduction stage. 2) Two rollers on railing and one support roller below. 3) Add hard-bristle brushes at the housing rail entrance and exit openings.	mazen
	Device falls off the rail ends and down the roof	1) No end cap for rails to prevent falling off rails. 2) Electronics or Motor malfunction causes chaotic movement.	10	7	10	700	1) Railings must have end caps to prevent falling off the roof. 2) Electronics programming should implement error catching measures to prevent hystrisis of components.	shamim
Water Management	Water leakage.	1) Poor swivel fitting design. 2) Excessive water pressure. 3) Incorrect assembly.	6	7	5	210	1) Use separate non-rotating water dispensing system. 2) Ensure fool-proof design for assembly. 3) Regulate pump power.	taraq
	Damaged or No/Reduced pump power.	1) Insufficient water in tank. 2) Faulty pump. 3) Blocked water path from tank.	8	7	7	392	1) Add low water switch. 2) Test pump thoroughly. 3) Correct pipe installation and size.	shamim
Cleaning	Improper water dispensing.	1) Not enough pressure. 2) Spinning brush roll shaft dispensing water everywhere. 3) Blocked pipe.	7	9	8	504	1) Separate water dispensing row. 2) Proper nozzle size.	arslan
	Brush roll poor/no cleaning.	1) Brush roll bristles do not reach the panel surface. 2) Low spinning speed. 3) Dirty, Matted or Frayed bristles from use.	8	5	3	120	1) Ensure long enough bristles. 2) Replace brush on schedule. 3) Ensure smooth rotation of brush roll shaft.	moaaz
	Wiper dragging on debris.	1) Poor cleaning process effectiveness. 2) Sticky debris stuck in wiper.	7	7	3	147	1) Cleaning effectiveness testing.	taraq
System control	power loss/power not reaching	circuit damage/control unit malfunction	9	4	9	324	ensure proper cable and circuit managment during installation/ensure that the circuit is covered properly to avoid environmental damage	ahmed
	system error preventing operation from commencing	improper coding/malfuntion of control unit	8	3	7	168	repeated testing of the coding to ensure capability of looping the function	mazen

Lastly, to wrap up the embodiment design, a failure mode analysis must be done. Hence, by identifying the critical sub-assemblies of the device, and their potential failure effect and causes, an RPN (Risk Priority Number) can be calculated to assess the risk numerically.

As tabulated in the table above, it is noted that each sub-assembly had its critical failures identified, with the potential effects and the required actions to resolve or work-around the problem. Lastly, each action was accompanied by the person-in-charge. The FMEA analysis was conducted according to the table, and can be found within Appendix-A under the Engineering Analysis section.

4.5 Performance Analysis

In order to judge the performance, the product had standards to meet. Firstly the product should be able to perform 1 cleaning cycle within 2 minutes, meaning that it moves up and down across the solar panel one time in 2 minutes. The user is then notified of the cleaning status and the cycle is concluded. In addition it is imperative that the cleaning cycle should not damage the solar panel whether that be by scratching the surface or ruining the solar panel circuit itself.

4.6 Engineering Analysis

Engineering analysis was conducted to determine the potential points of failure as well as to calculate and find the necessary requirements of design to ensure that the device is operable. Hence, with the outlined FMEA actions tabulated in table 4-5, section 4.4, the parameters to be analysed were as follows:

- Gear train analysis.
- Gear surface analysis.
- Gear tooth bending strength
- Motor selection
- Bearing selection
- Shaft analysis
- Pump selection criteria.

(It is noted that only a summary for each analysis is discussed, and further details can be found by referencing the full analysis documents for each section attached in the Appendix.)

Motor Selection

By assuming a standard velocity and the known length of the solar panel the device has to travel along. Coupled with the assumed gear ratio of the system which balances the device on an inclined angle of 15 ~ 30 degrees according to the inclined rooftop setting, the motor to be selected would require a torque of 2 Nm with rotational speed between 500 ~ 1000 rpm. Hence, referencing a commercial catalog (Hiwin Motors, 2024), a suitable motor to pick would be the DMS12G as it fits both the Torque and Speed requirements as shown in the figure below.

Table 1.3 DMS1 Specifications

	Symbol	Unit	DMS12G
Continuous torque	T_c	Nm	5
Continuous current	I_c	A_{rms}	4
Peak torque (Within 1s.)	T_p	Nm	15
Peak current (Within 1s.)	I_p	A_{rms}	12
Torque constant	K_t	Nm/A_{rms}	1.25
Electrical time constant	T_e	ms	3.2
Resistance (line to line at 25°C)	R_{25}	Ω	2.6
Inductance (line to line)	L	mH	8.2
Number of poles	2p		22
Back emf constant (line to line)	K_v	V_{rms}/(rad/s)	0.6
Motor constant (line to line at 25°C)	K_m	$Nm/\sqrt{W}$	0.6
Thermal resistance	R_{th}	K/W	1.2
Temperature sensor			
Nominal input voltage		V_{DC}	
Inertia of rotating parts	J	kgm^2	0.006
Mass of motor	M_m	kg	7.2
Max. axial load	F_a	N	3700
Max. moment load	M	Nm	60
Max. speed		rpm	600

Figure 4-2: HIWIN Motors Selection Catalogue

Gear Train Analysis

In particular the gear train for this device was designed twice. Though overall, the primary objective of the gear train was to achieve a reduction of (20), the first design was not efficient as it consumed too much space, furthermore, its large size made it difficult to fabricate. Hence, the design was reiterated using axle connections and the gear train managed to achieve its intended reduction ratio of 20:1 at 1/5th size. A detailed sketch of the Gear Train Analysis can be found attached in the Appendix.

Gear Tooth Bending

Utilizing gear tooth bending equations, the effective fatigue stress for the critical idler gear w was determined to be the idler was 12.558 ksi with a maximum power transmission of 0.9459 hp. As the maximum possible power being transmitted was closer to 0.3 hp, the system had an approximate safety factor of (4). Hence, indicating that the gear teeth were safe from bending and fatigue.

Gear Tooth Surface

The surface fatigue of the gear was determined to be 212.06 sqrt(psi), the surface endurance strength is 0.84 ksi. Hence, it was that due to the lack of major pressure applied to the gear tooth surface, it would withstand the operation of the device.

Shaft Analysis

Following this, the bending stress for the shaft was calculated to be 22.26 MPa which gives us a SF of 11 when compared with the material's yield strength.

Roller shaft analysis

In addition to that the analysis was done for the side rollers that help the device move across the panel, the shear stress experienced by the roller shafts is 6.66 kpa which gives us a shear safety factor of 12, and the bending stress is 171.056 kpa which gives a safety factor of 87.

Bearing Selection

For the bearing selection it was determined that since the critical force applied through the maximum possible power transmission was too less to impact bearing performance, any light-series bearing larger than the minimum 16 mm-size allocated would be applicable for this device's operation.

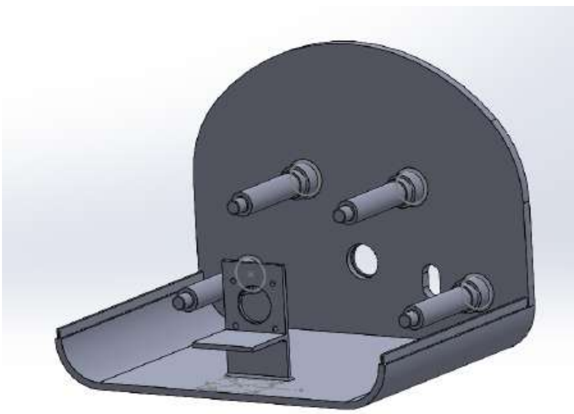
Pump Selection

The pump we required to meet the flow requirements for the device is one that can utilize a minimum 0.77 W of power continuously. Further analysis can be referenced in the appendix.

4.7 CAD Modelling

This section collectively illustrates the 3D model representing the actual device as well as the modified prototype model. The models were created and simulated through SolidWorks.

4.7.1 Actual Heliocentric Rooftop Solar Panel Cleaning Device modelled parts



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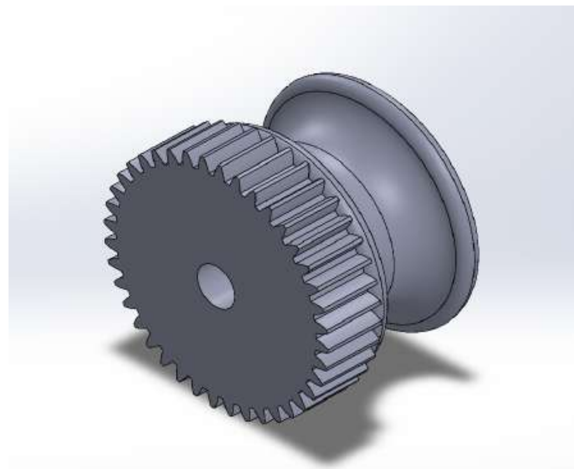

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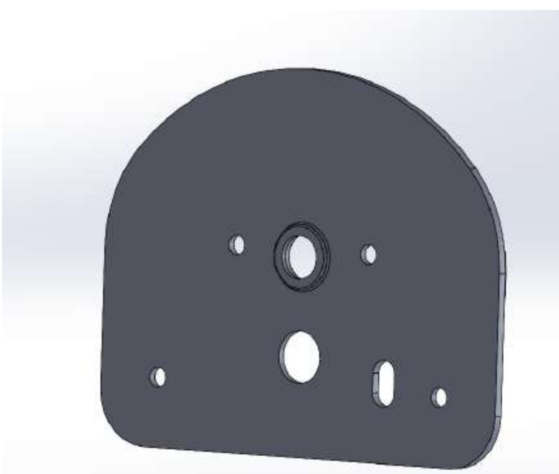

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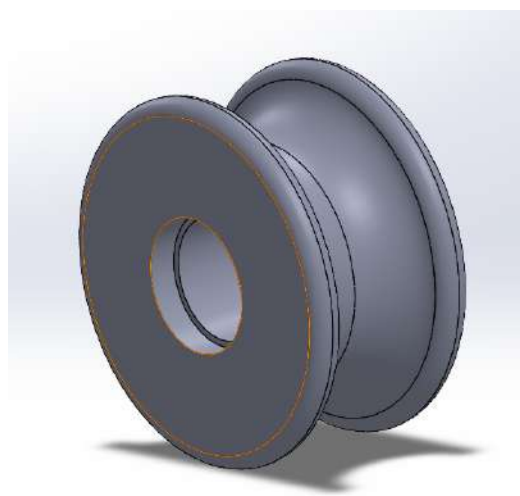
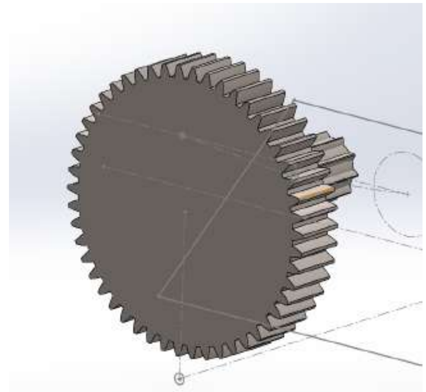


D.

Figure 4-3 CAD Modelling. A) Housing Base. B) Roller Gear C) Gearbox Support Plate. D) Support roller.

A.



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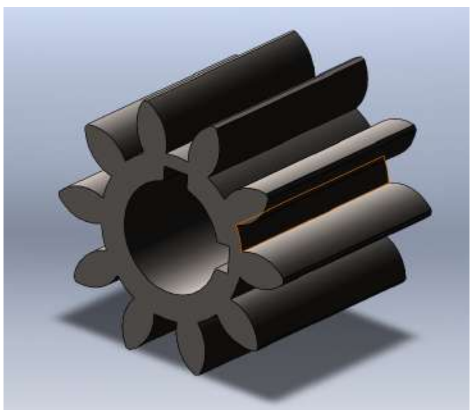

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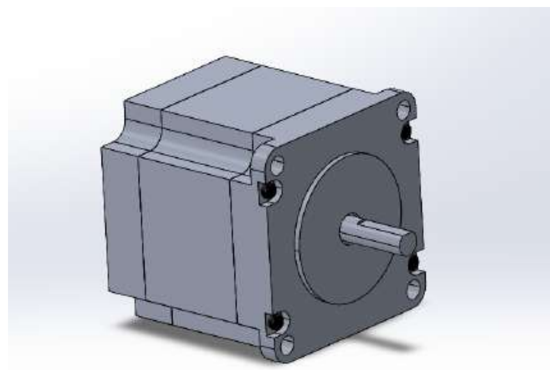
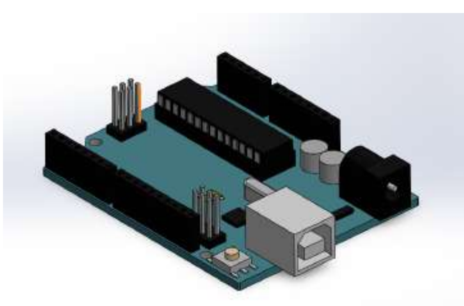
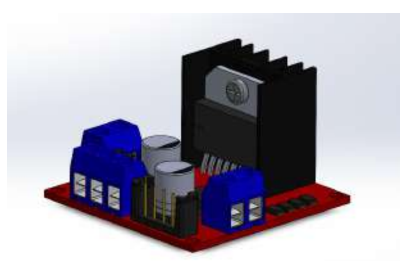


D.

Figure 4-4: A) Input Shaft. B) Idler Gear. C) Input Pinion. D) Torque Motor.



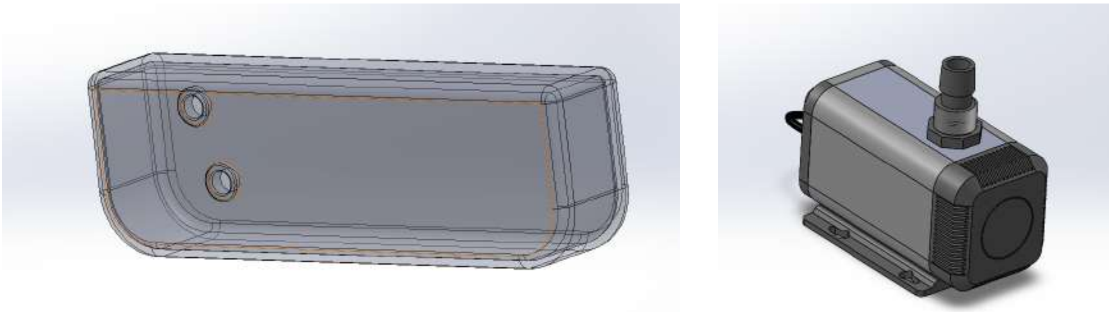
A.



B.

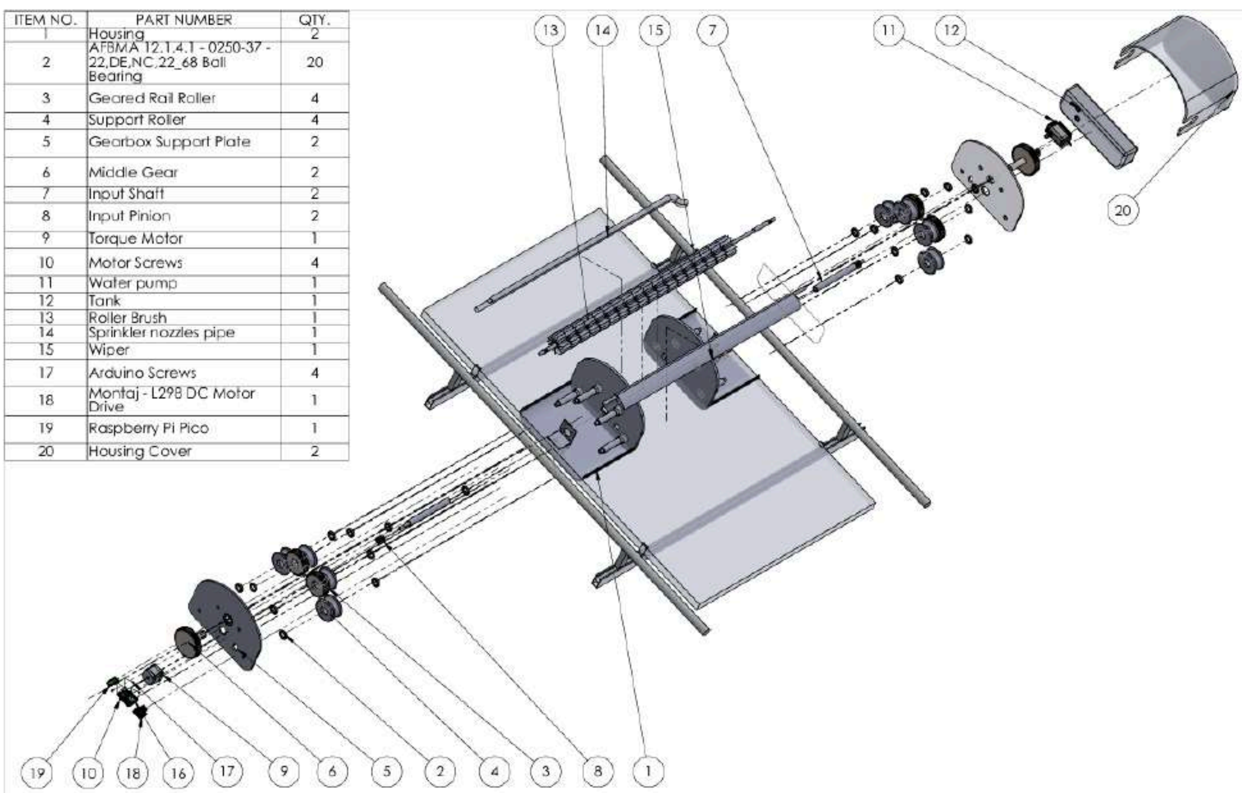
C.

Figure 4-5: A) Arduino Uno. B) Motor Driver. C) Raspberry Pi Pico.



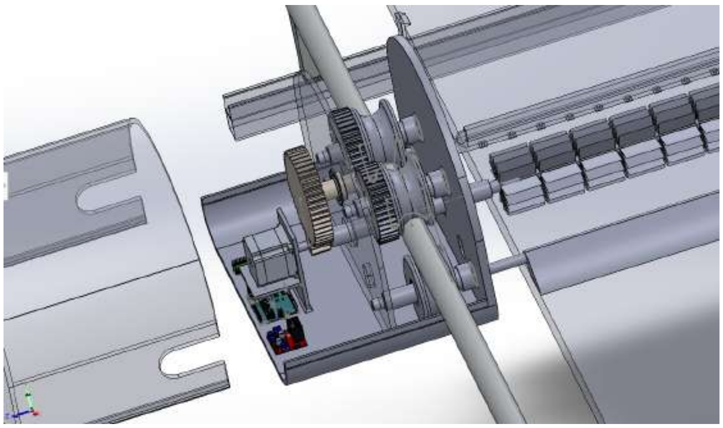
A. B.

Figure 4-6: A) Water Tank. B) Water pump.



ITEM NO.	PART NUMBER	QTY.
1	Housing	2
2	AFBMA 12.1.4.1 - 0250-37 - 22,DE,NC,22_68 Ball Bearing	20
3	Geared Rail Roller	4
4	Support Roller	4
5	Gearbox Support Plate	2
6	Middle Gear	2
7	Input Shaft	2
8	Input Pinion	2
9	Torque Motor	1
10	Motor Screws	4
11	Water pump	1
12	Tank	1
13	Roller Brush	1
14	Sprinkler nozzles pipe	1
15	Wiper	1
17	Arduino Screws	4
18	Montaj - L298 DC Motor Drive	1
19	Raspberry Pi Pico	1
20	Housing Cover	2

Figure 4-7: Exploded View of Assembly.



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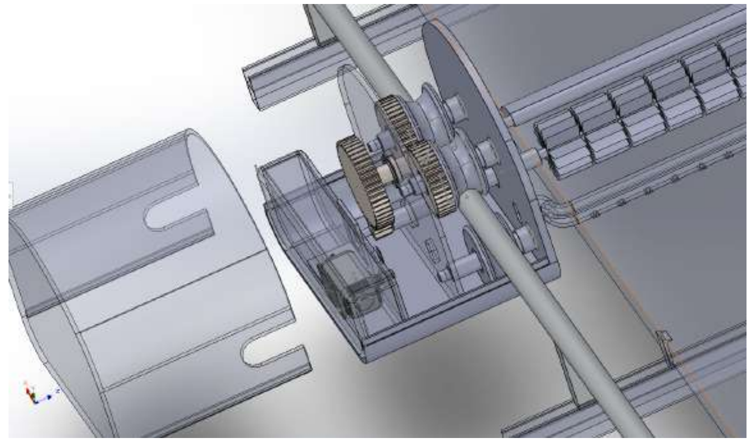

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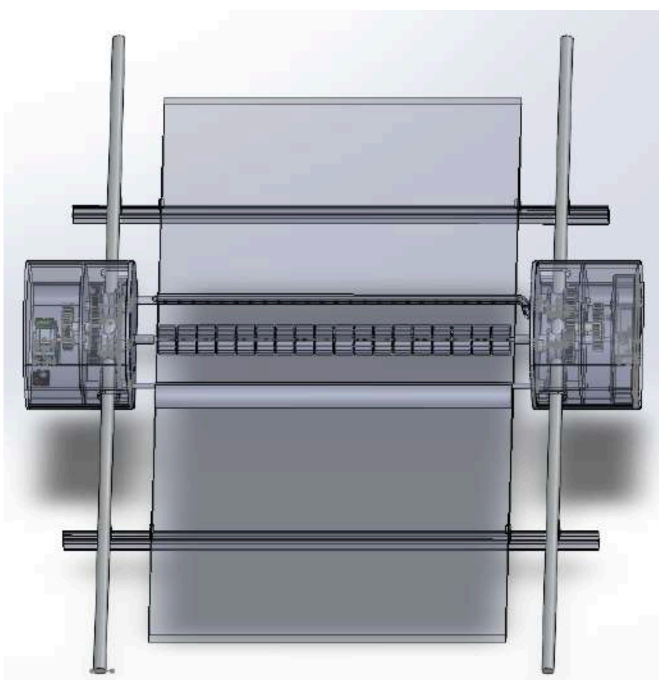


C.

Figure 4-8: Assembled CAD Model. A) Motor side. B) Pump side. C) Assembled Device.

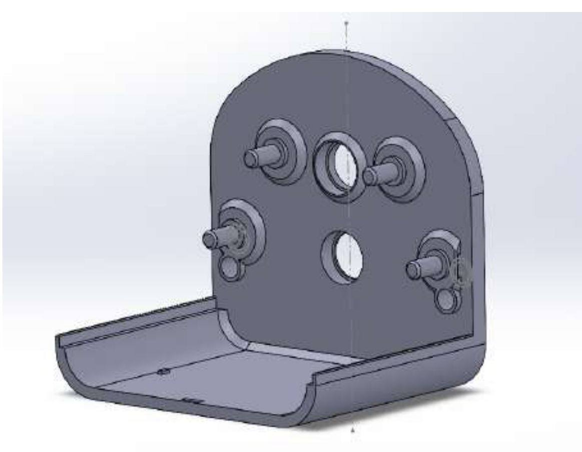
4.7.1.1 Actual Device Costing Estimation

Table 4-6: Estimated Cost Breakdown for Solar Panel Cleaning Device

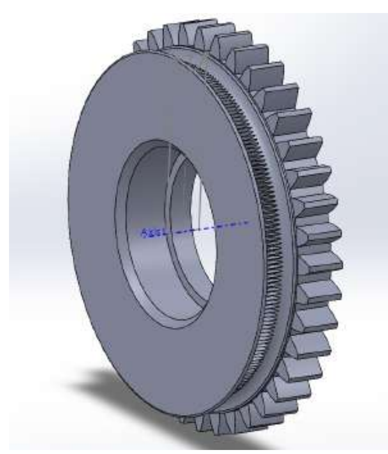
ITEM NO.	PART NAME	QUANTITY	ESTIMATED UNIT COST (MYR)	TOTAL COST (MYR)	SOURCE (SHOP LINK)
1	Housing	2	50	100	Manufactured
2	AFBMA 12.1.4.1 - 0250-37 - 22,DE,NC,22_68 Ball Bearing	20	10	200	Shop Link
3	Geared Rail Roller	4	40	160	Manufactured
4	Support Roller	4	30	120	Manufactured
5	Gearbox Support Plate	2	35	70	Manufactured
6	Middle Gear	2	25	50	Manufactured
7	Input Shaft	2	30	60	Manufactured
8	Input Pinion	2	20	40	Manufactured
9	Torque Motor	1	250	250	Shop Link
10	Motor Screws	4	5	20	Included
11	Water Pump	1	150	150	Shop Link

12	Tank	1	100	100	Manufactured
13	Roller Brush	1	80	80	Shop Link
14	Sprinkler Nozzles Pipe	1	50	50	Shop Link
15	Wiper	1	40	40	Shop Link
16	Arduino Screws	4	5	20	Included
17	Montaj - L298 DC Motor Drive	1	35	35	Shop Link
18	Raspberry Pi Pico	1	50	50	Shop Link
19	Housing Cover	2	40	80	Manufactured
Total Estimated Cost				**1675 MYR**	

4.7.2 Prototype modelled parts of Heliocentric Rooftop Solar Panel Cleaning Device



A.



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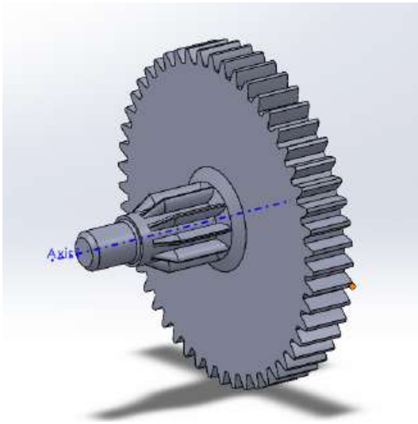

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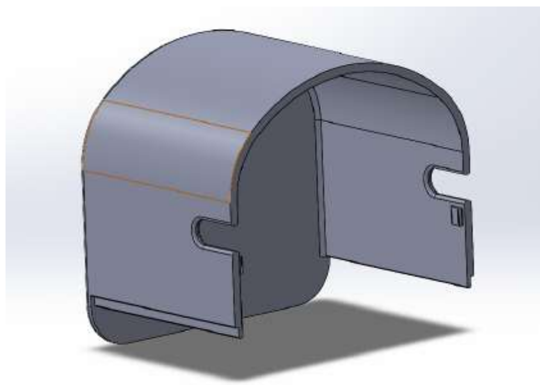
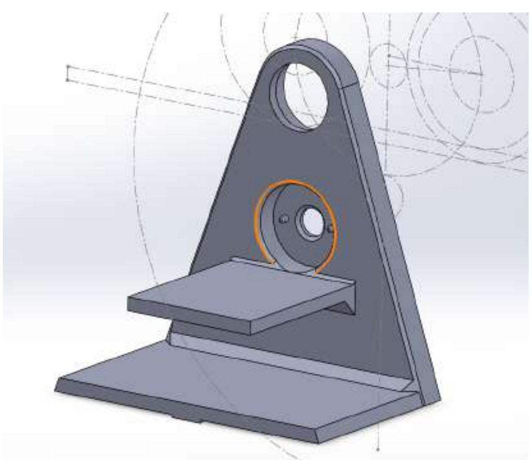
D.



E.

Figure 4-9: All prototype components. A) Housing. B) Roller Gear. C) Idler Gear. D) Input shaft pinion and follower shaft pinion. E) Housing Cover.



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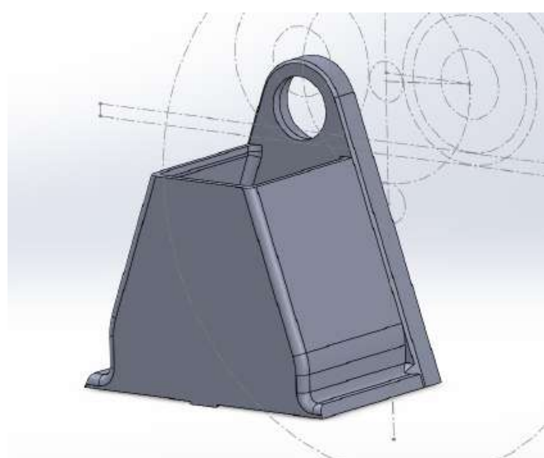


B.

Figure 4-10: A) Middle Piece Motor side. B) Middle Piece Pump side.

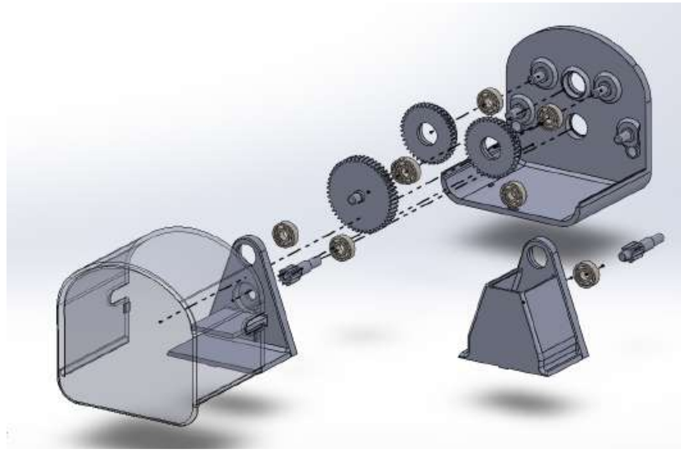


Figure 4-11: Prototype Exploded View.

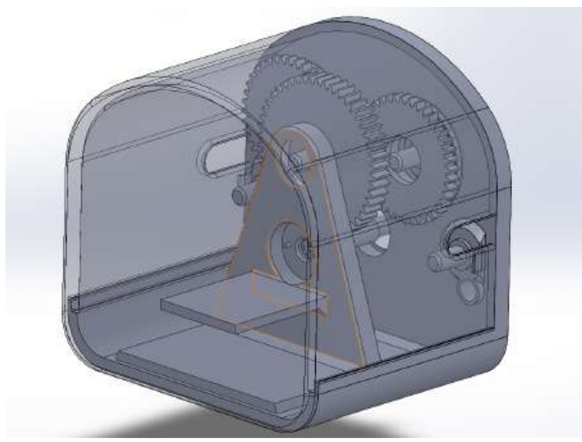


Figure 4-12: Prototype Assembly.

5.0 Results and Discussion

5.1 Initial Prototyping

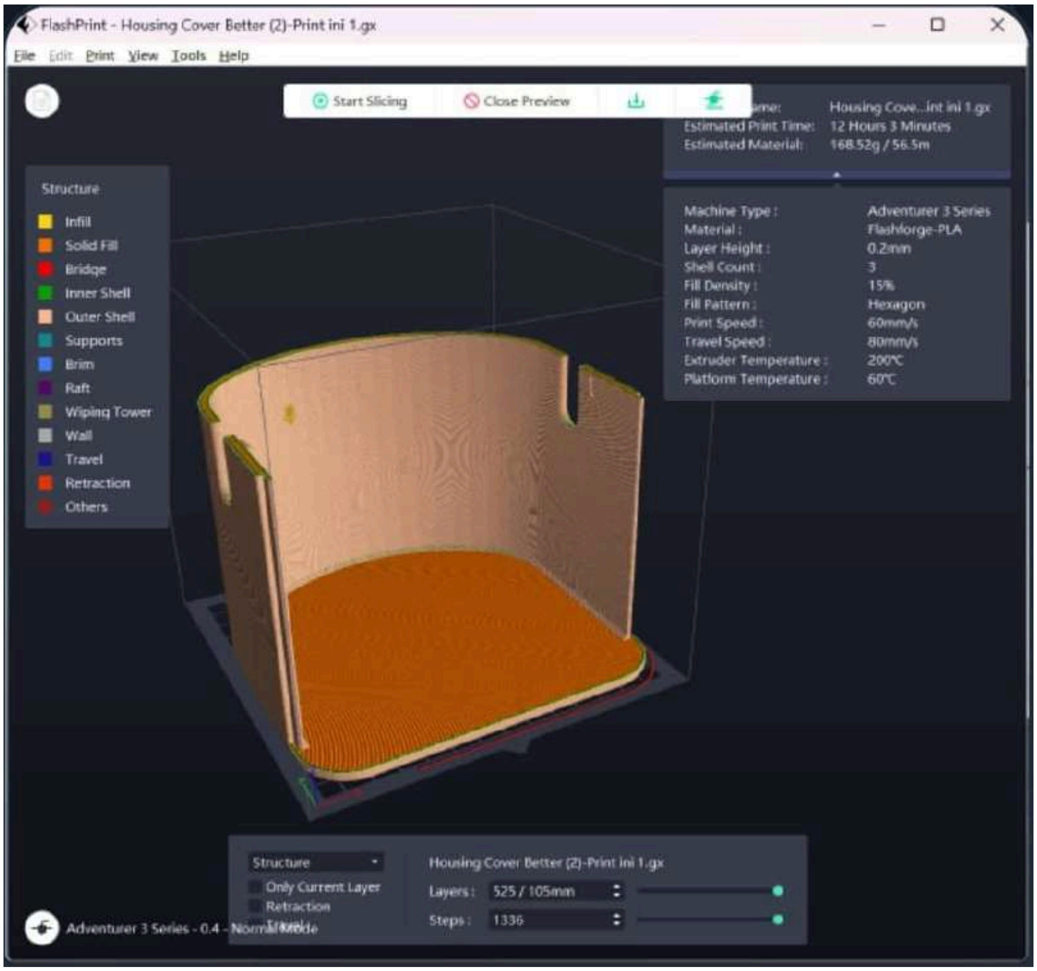
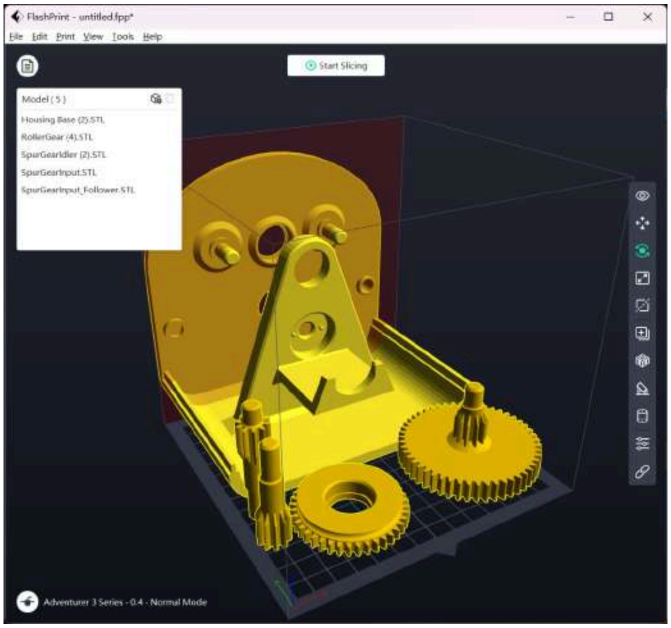


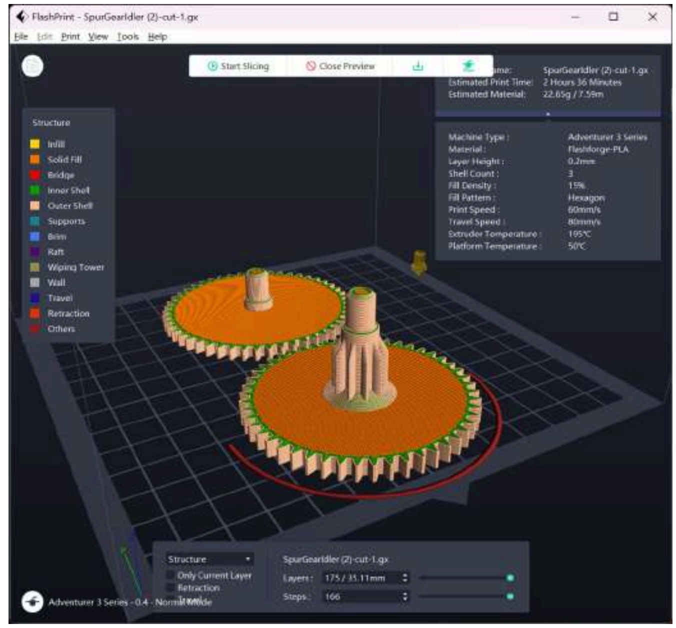
Figure 5-1: Prototype Fabrication Interface

Following the 3D model generated through solidworks, the next step was to fabricate the prototype. However, as discussed in the scope, this project's prototype is limited to a scale model due to limitations in obtaining components suitable for full-size rooftop solar panels. Hence, the prototype is within 1/10th and 1/15th scale. Since the prototype would be a scaled model, the HDPE was substituted for a more readily available polymer and the prototype was 3D printed using FDM as shown in figure 5-1.

Hence, the CAD models shown in section 4.7 of this report were entirely 3D printed due to their custom geometries. The following figures showcase the printing interface.



A.



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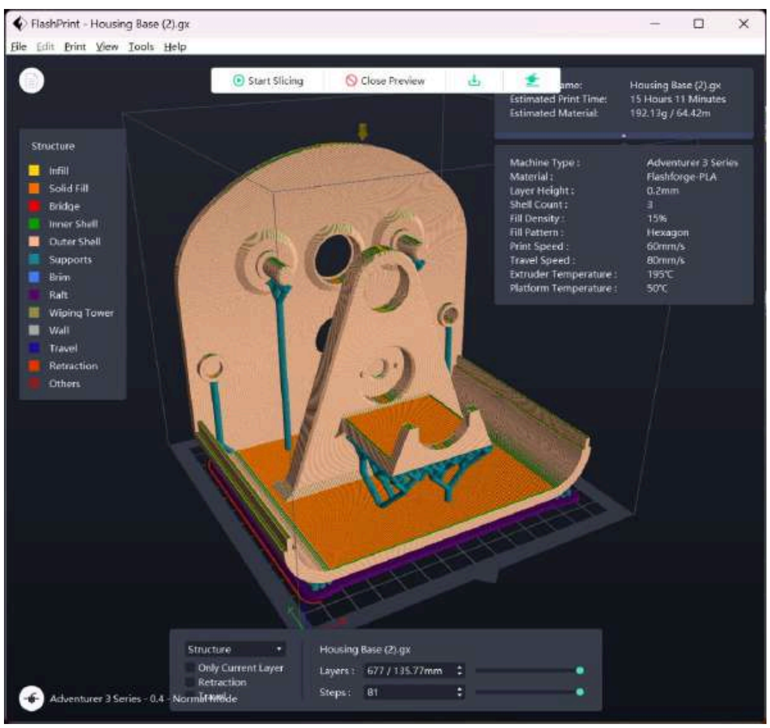

C.

Figure 5-2: 3D printing prototype. A) Initial Printing. B). Gear Printing. C) Housing Printing

However, with the prototype being fabricated using FDM 3D printing, it is probable that there were some errors. The following figure showcases a particular error faced during fabrication.

Figure 5-3: Printing Errors

As can be seen illustrated in the figure above, in this particular scenario the flowrate of the FDM 3D printer was not up to requirement, hence resulting in flaky and wafer-like 3D print that is not stable. This is classified as a systematic error as the 3D printer itself is at fault. Though these issues are rare, they are sometimes unavoidable when printing complex geometries at small scale printers.

Once the prototype parts were fabricated, the gears were assembled to recreate the gear train onto the housing base. The motor is then inserted into the slot to check for gear meshing and overall accuracy of printing.

Figure 5-4: Initial Assembly of Prototype

Following this, the prototype can be assembled onto a rig to continue its assembly process. The figure below illustrates the initial assembly of the prototype on a strawboard rig. The stainless steel railings simulate the roof mounted supports along a solar panel. Once assembled, the gear train is checked for rotational ability, to ensure the gear tolerances are within acceptable limits.

Figure 5-5: Prototype Rig Assembly

With the rig assembled, the remaining parts to assemble are the electronic circuits which need to be mounted onto the housing beside the motor. The circuit follows a simple schematic shown below. (Note: No breadboard is utilized within the circuit, the wires are directly soldered onto the motor and plugged into the arduino)

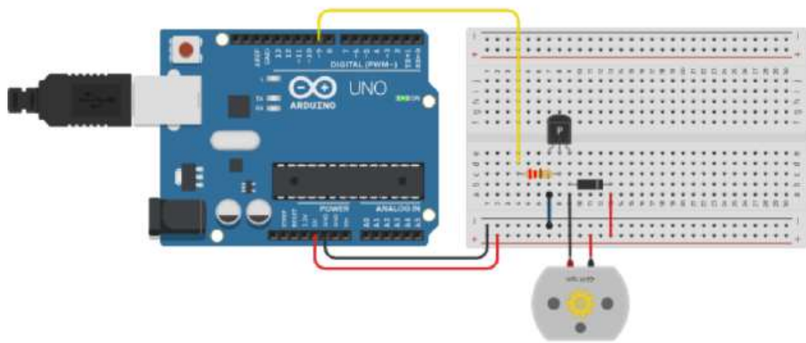

Figure 5-6: Motor Wiring Schematic

To simplify the wiring process and remove external resistors, an L298N motor driver is used. This driver allows the motors to be plugged in and used immediately through an external power source. The L298N driver takes two motors as input. In this particular case, the following figure illustrates the wiring diagram. (Note. Motor B represents the water pump as both work on the same electric principles)

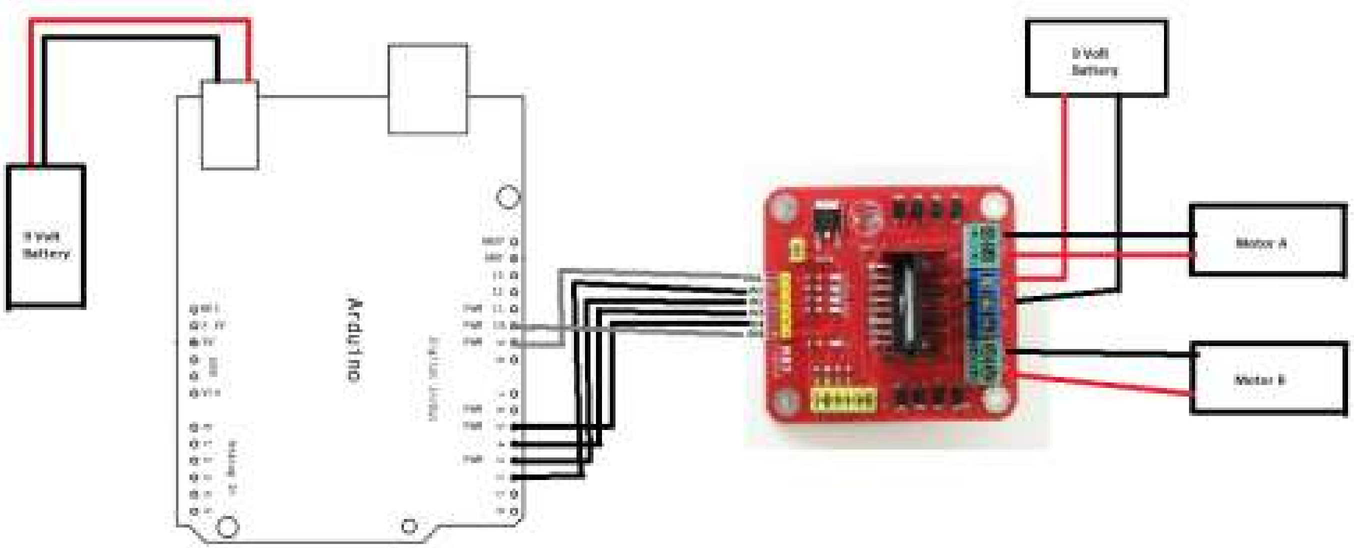

Figure 5-7: L298N Wiring Schematic with Arduino

Lastly, as this prototype requires a way to notify the user and to start the process, a Raspberry Pi Pico W board is used to serve as a wifi connector. The Pico W connects to the Blynk IoT server through a mobile phone, allowing the user to control the machine using an app.

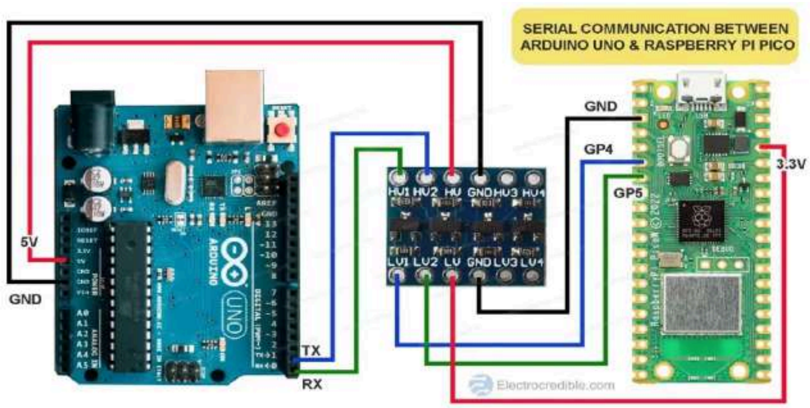

Figure 5-8: Raspberry Pi Pico W Wiring to Arduino

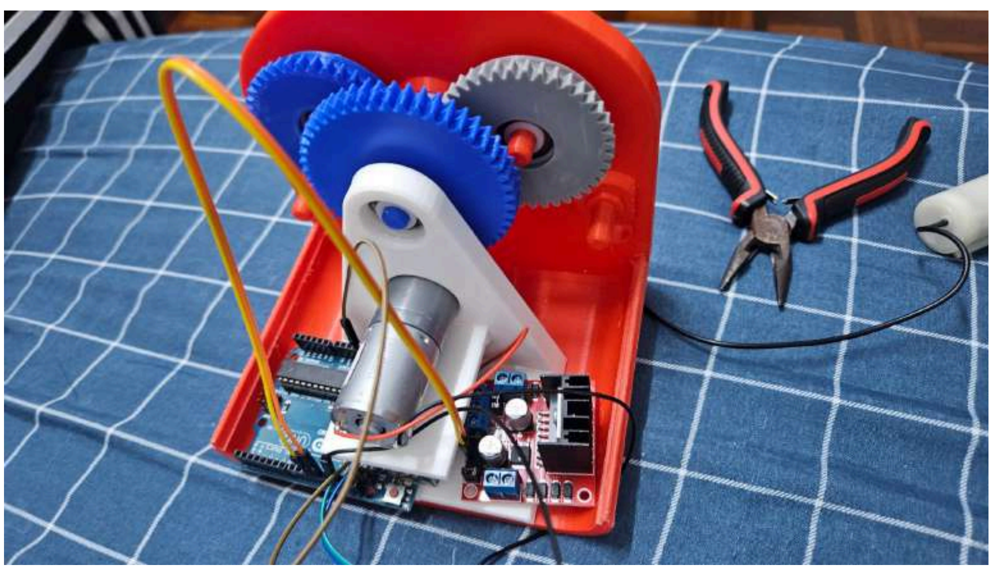

Figure 5-9: Completed wiring Schematic

The figure above illustrates the completed wiring schematic mounted onto the prototype. Once the cover is put on, the wiring is completely hidden and cannot be seen. This full assembly of the prototype is shown in the figure below.

Figure 5-10: Fully Assembled Prototype (With Cover)

5.1.1 Prototype Costing

Most of the components in this prototype were 3D printed using FDM which was either facilitated by the FKM Printing Lab or was paid for at a rate of 0.3 RM/g.

Table 5-1: Detailed cost of prototype components.

No.	Part Name	QTY.	Source	Cost (RM/piece)	Total Cost (RM)
1	Housing Base	2	FKM Lab + Paid 3D printing service	1pcs no charge + 1pcs (100)	100
2	Roller Gear	4	FKM Lab	UTM covered	0
3	Idler Gear	2	FKM Lab	UTM covered	0
4	Input Pinion	1	FKM Lab	UTM covered	0
5	Input Follower Pinion	1	FKM Lab	UTM covered	0
6	Middle Piece Motorside	1	FKM Lab	UTM covered	0
7	Middle Piece	1	FKM Lab	UTM covered	0
8	Ball Bearings	15	Shopee	1.16	17.5 +5 delivery
9	Housing Cover	2	FKM Lab	UTM covered	0
10	Arduino Uno	1	Shopee	40	40
11	Raspberry Pi Pico	1	Shopee	26	26
12	L298 DC Motor Drive	1	Shopee	6	6
13	Torque Motor	1	Shopee	29	29
14	Water Pump	1	Shopee	3	3
Total Cost (RM)					226.5

5.2 Testing

Once fully assembled, the prototype was put through rigorous testing to ensure its functionality. Firstly, to begin testing, the Blynk IoT app page was crafted as shown in the figure below.

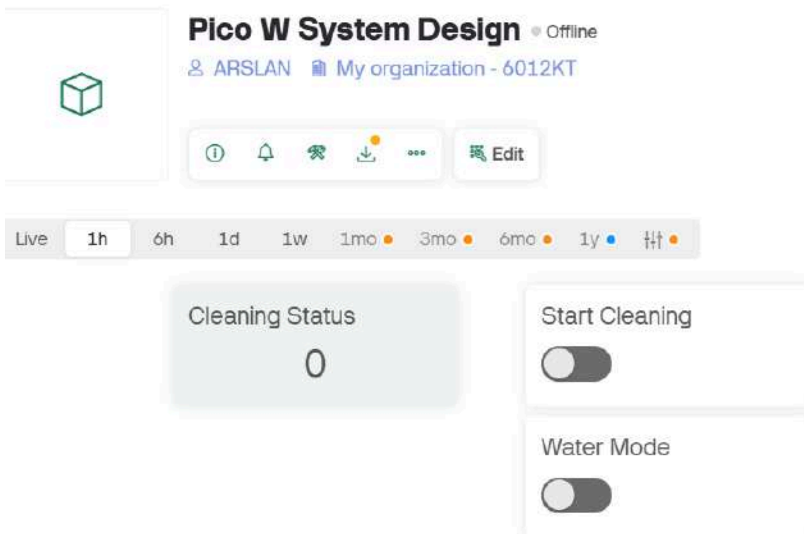

Figure 5-11: Blynk IoT App Interface

As shown above, the Blynk app interface has two buttons and one status indicator. Once the start button is pressured the prototype begins cleaning. However, in this particular case, it is only using the brush to scrub. But, if the water mode switch is clicked, the cleaning starts again, this time utilizing the pump to sprinkle water through the tubes–This wets the surface of the panel and allows for better cleaning.

Figure 5-12: Prototype Testing in Progress.

As can be seen in the figure above, the prototype was tested multiple times in its cleaning mode and the following time data was collected.

Table 5-1: Cleaning Data

Iteration	Cleaning Time Taken (s) (2 Cycles)
1	86
2	79
3	83
4	77
5	74
Average Time Taken	79.8

Analyzing the data obtained from the table above and comparing it with the requirements of the performance analysis, it was noted that the scaled model prototype completed two cycles of cleaning faster than the expected time of 120 seconds. Perhaps this increase in speed could be attributed to lower density polymer being used as base material which allowed the motor to exceed the expected speeds. However, when the water mode was utilized, the following data was obtained.

Table 5-2: Water Mode Cleaning Data

Water Mode Iteration	Cleaning Time Taken (s) (2 Cycles)
1	96
2	89
3	87
4	83
5	79
Average Time Taken	86.8

Observing the table above, it can be noted that evidently as the pump was used the time taken for the cleaning cycles was increased. This was primarily due to the fact that as the pump is being used, initially the rig must stay at its position to allow the water to flow across the panel's surface. Hence, this small delay can build up across two cycles, resulting in an increased time taken. However, it was also noted that despite this, the prototype completed the cleaning cycles within the expecting limits, and cleaned the surface efficiently.

5.3 Discussion

The Rooftop Solar-Panel Cleaning Device brings substantial improvements to solar panel maintenance through its development. Environmental factors determine how much power output solar panels will lose because of dust accumulation because analysis shows a reduction between 15 and 30 percent. Regions that experience dust storms and low rainfall levels in dry climates are most impacted by this phenomenon. The research developed an integrated cleaning system for residential and small-scale commercial rooftop solar panels which provided budget-friendly and sustainable automated cleaning besides eliminating customary manual washing. The project discussion examines the basic components of the solution through exploration of its design elements and functional performance and the encountered barriers and their value for upcoming technological developments.

The project's main success comes from implementing a motorized gear train system to convert rotational power into linear movement of solar panels. This system delivers reliable quality cleaning operations which protect the entire photovoltaic area. The brush equipment with its extended length across the complete panel width offers an inventive dust and debris removal method through scrubbing operations. The designed system supports the project's water conservation goal by reducing water consumption while staying free from chemical reactions which makes it favourable for water-shortage areas. The device construction uses aluminium together with durable plastics to achieve lightweight composition which prevents excessive stress on solar panel supports and roof structures.

During the comprehensive embodiment phase of the project designers apply Design for Manufacturing and Assembly (DFMA) strategies to achieve optimal device design. The team achieved three major benefits by simplifying the assembly process through their reduction of parts from 78 to 57 components. As a result both production costs and product reliability saw substantial improvement. The simplified design provides increased manufacturability and decreases mechanical failure risks when the device operates. The selection of materials used for the device followed three principles: maintaining cost efficiency combined with long-lasting performance alongside environmentally friendly standards to create an affordable sustainable solution. The need for sustainable operations in renewable energy systems finds alignment with the implementation of recyclable and non-toxic materials.

Performance analysis settled the device requirements by needing it to finish one cleaning operation within two minutes and perform the process without causing harm to solar panels. The device passed the tests which demonstrated its capacity to remove dust and debris efficiently as it elevated solar panel efficiency. The design received additional evaluation through engineering analysis to determine essential variables like motor torque together with gear train ratios as well as bearing load capacities. The motor selection provided 2 N.m minimum torque and the gear train reached its best performance at a ratio of 20. The chosen bearings achieved at least 260N minimum supporting force to maintain operational stability of the device. The device could operate reliably under different environmental conditions after these tests determined its capacity to endure heavy rain and windstorms.

The project encountered multiple difficulties needing thoughtful assessment despite its previous achievements. Primarily the team needed to confirm the device operated independently from human control. Users gained remote managing capabilities through integrated smartphone systems that enabled them to track and direct the cleaning operations. Functionality and cost-effectiveness presented a challenge to the device since homeowners needed an affordable yet high performing product. Team leadership determined a pricing solution of RM 5K as their target to reach a market-affordable yet feature-rich product. The modular construction of the device makes it simple to set up and service which results in decreased maintenance expenses in the long run.

The project incorporates sustainability principles through its selection of recyclable non-toxic materials to reduce environmental effects. The device cleans photovoltaic surfaces without abrasion thus it protects their longevity and improves power output. The system's sustainability orientation coordinates with the core renewable energy vision since it works to cut fossil fuel usage while protecting the environment. Since this device operates without water needs it becomes suitable for arid regions which experience serious water shortages.

The Rooftop Solar-Panel Cleaning Device provides an environmentally friendly cost-effective solution which enhances solar panel energy generation and extends their operational life span. The device combines engineering concepts with sustainable materials and user-friendly capabilities to provide environmentally-minded property owners and businesses with improved solar power investment returns. The upcoming research activities should aim to improve the device's power efficiency and develop AI-based predictive repair systems and deploy these solutions to bigger solar power facilities. The presented project shows how mechatronic systems can transform solar panel maintenance processes which creates opportunities for sustainable energy development.

6.0 Conclusion

Overall, the objective of this report to design and develop a rooftop solar panel cleaning system was successfully achieved. Furthermore, a scaled prototype was fabricated to showcase the functionality and electronic automated control of the design. It was noted that the prototype was successfully able to be remote controlled using the Blynk IoT app. The app allowed its users to start or stop the cleaning process, and choose between water cleaning or simply scrubbing of the panel's surface. Lastly, it also indicated when the cleaning session was over. Through the data collected, it was found that the prototype's speed was within expectations as it took an average of 78 seconds to finish while only scrubbing and approximately 89 seconds to finish with water cleaning. But relative to the expected 120 seconds to complete two cycles of cleaning, the prototype proved to be faster–Likely due to its lower weight.

In conclusion, the study successfully achieved its objective as the team produced a working electronically automated residential rooftop solar panel cleaning device that utilizes an efficient system to save on space and power costs.

7.0 References

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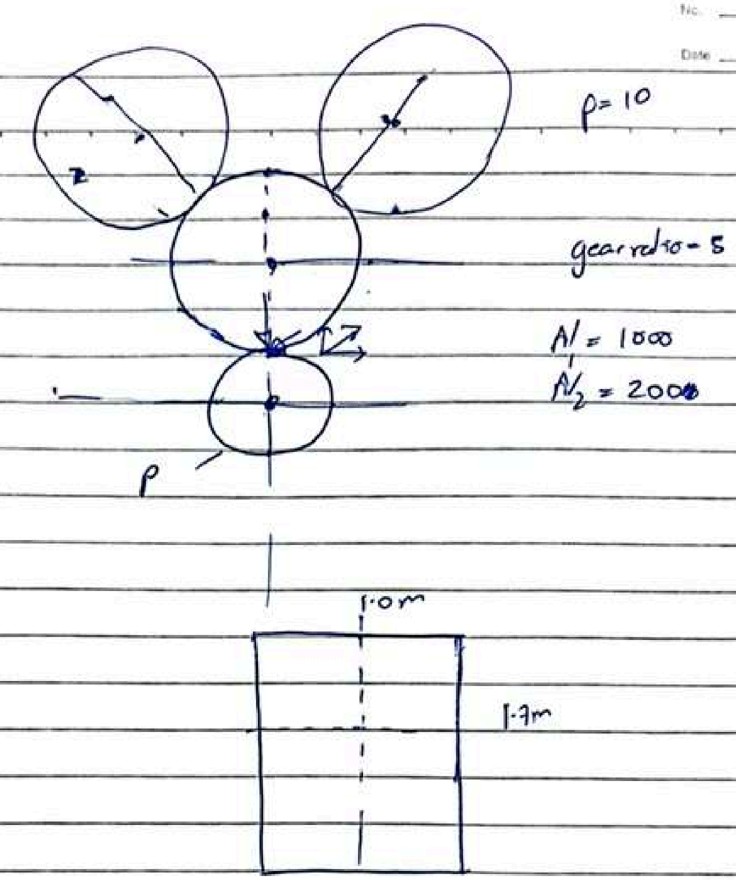
Appendix

Appendix -A Engineering Analysis

1-Motor selection , done by Mazen Mohamed



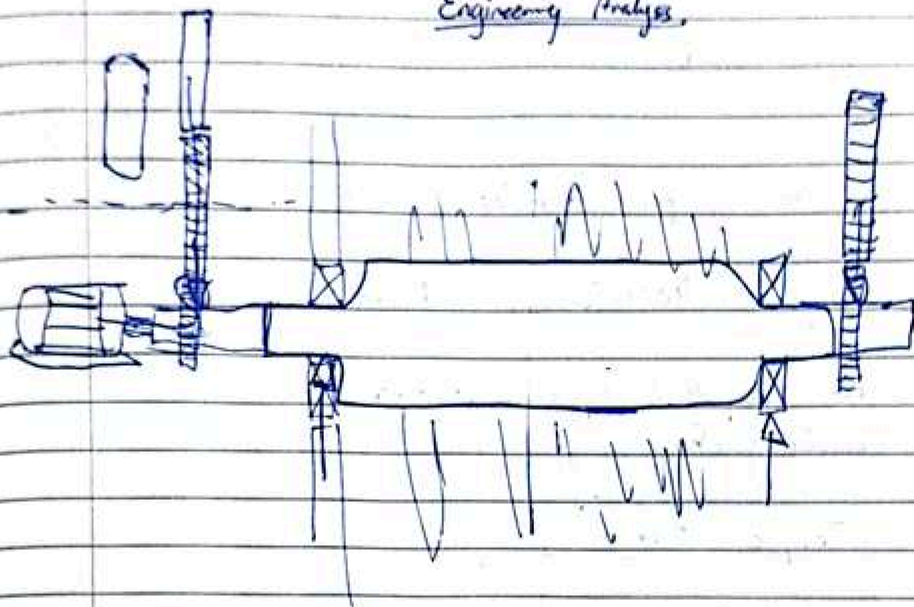
assume velocity by distance covered in 1 minute

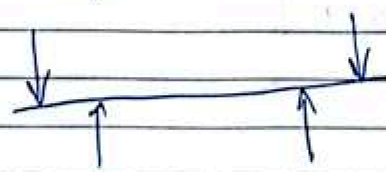
$$V = \frac{1.7}{60} = \frac{1.7\,m/s}{60}$$

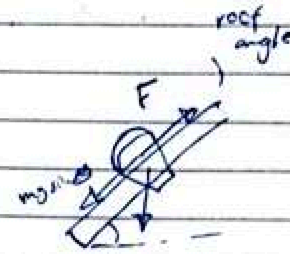
$$\boxed{V = 0.0283\ m/s}$$

∴ assume 1000 rpm for brush

Engineering Analysis.







Motor-Selection

$\theta = 15° - 23°$

(roof angle) (assume 23°)

- Assuming weight to move is 5 Kg

Force required = $mg\sin(23) = 5 \times 9.81 \times \sin 23 = 19.1638$ N

Safety Factor = 2

Hence, force required = 38.33 N

Hence, select motor based on force (40N) and rpm (500.-1000).

Date

Motor Selection

∵ assuming pinion diameter of 5 cm

Torque = $40N \times (0.025) = 1\ N.m$

For Safety & Efficiency ; Add another safety factor.

$\boxed{\text{Torque} = 2N.m}$

$\boxed{\text{Total Safety Factor} = 4}$

2- Gear train analysis, done by Muhammad Arslan

Spur gear analysis

(face width)

$\frac{9}{P} < b < \frac{14}{P}$

hence assume $b = \frac{10}{P}$

b = 1 inch or 0.9 inch

∵ Assume Circular pitch / diametral pitch

$p = \frac{\pi d}{N}$ (d is pitch diameter)

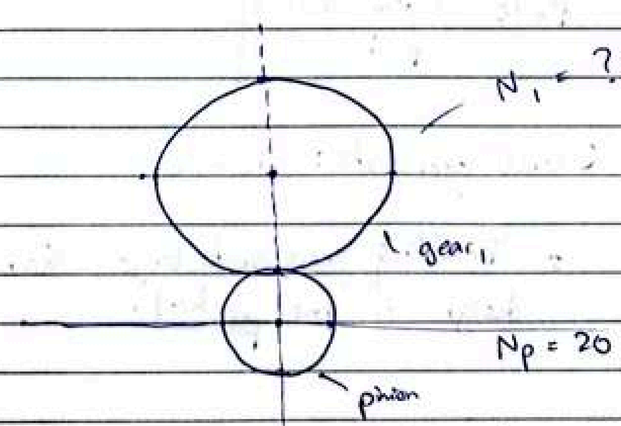
diametral pitch $\left(P = \frac{N}{d}\right)$ teeth per inches

– Assume P = 10 $\left\{ d = 5\text{cm or } 1.97 \text{ inches} \right\}$

$10 = \frac{N}{1.97}$

$\boxed{N_p = 19.7 \text{ or } 20 \text{ teeth}}$ $\Big\{$ number of teeth on pinion

Gear train



assume gear ratio = 5

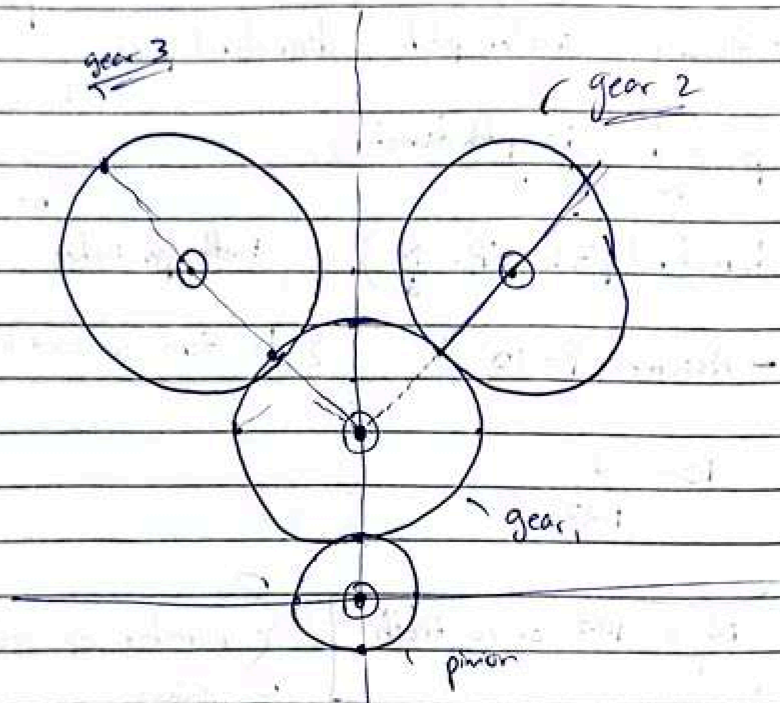
$\frac{N_1}{N_p} = 5$; $N_1 = 100$

$d_p = 1.97$ in

$d_1 = 9.85$ inches (for big)

Engineering Analysis

Full- Gear Train (design-1)



P=10 (diametral pitch)

Overall gear ratio: 10-20

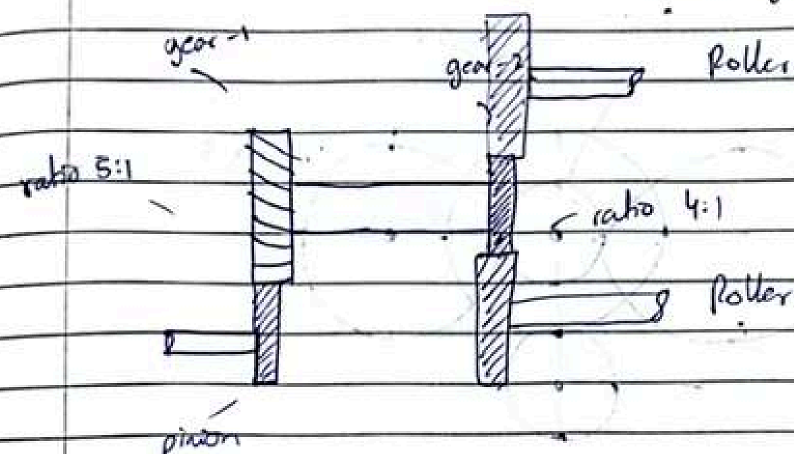
∴ Resulting gears are too large; Gear train design is not practical.

Redesign

Engineering Analysis

(design-2)

gear-train (side view) - New design to achieve overall gear ratio of 20.

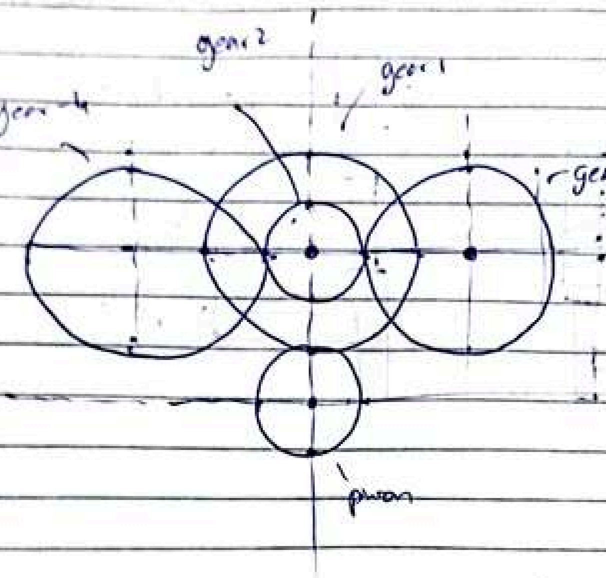


- Saves space

- Economical as achieving gear ratio without large difference in gear size.

Engineering Analysis

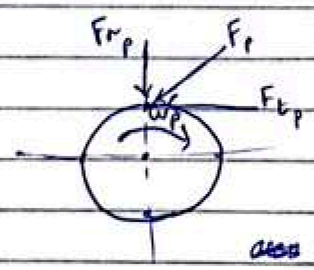
Design (3)



$N_p = 10$
$N_1 = 50$
$N_2 = 10$
$N_3 = N_4 = 40$

gear-tooth

∵ Assuming $n_p = 1000\,rpm$



∵ assuming Torque = 2.3 Nm

Power = $T\omega$

$\omega_p = 104.72$ rad/s

Power = 240.856W

or

Power = 0.322 hp

Date

Calculate F_{tp}; $F_{tp} = \frac{\dot{W}}{V}$

$F_{tp} = \frac{240.856}{V}$ $\Big\{$ $V = \frac{\pi d n}{60{,}000} = \frac{\pi \times 25.4 \times 1000}{60{,}000} = 1.3299$

$\boxed{F_{tp} = \frac{240.856}{1.3299} = 181.11\ N}$

$F_{rp} = F_t \tan(\theta) = 181.11 \times \tan 20 = 65.919\ N$ #

<u>Gear-tooth strength Analysis</u>

∴ only done on critical gear (~~pinion~~ idler)

- Assume full load applied to tip of single tooth
- Assume F_r is negligible
- Assume load uniformly distributed across face width

$\sigma = \frac{F_t P}{bY}$ $\Big\{$ $P = 10$, $F_t = 181.11N$; $b = 1\ inch$, $Y = 0.201$

~~Bearing Selection~~

Engineering Analysis : $\boxed{\text{Gear-Tooth}}$

$$\sigma_{max} = \frac{F_t P}{bJ} K_v K_o K_m \quad \left\{ \begin{array}{l} K_v = 1.373 \\ K_o = 1 \\ K_m = 1.6 \end{array} \right. \quad \begin{array}{l} P = 10 \\ b = 1 \\ J = 0.201 \approx Y \end{array}$$

$$\sigma_{max} = F_{t\,max} \left(\frac{10}{1 \times 0.201} \right) 2.1168 = 105.3134\, F_{t\,max}$$

$$S_n = S'_n C_L C_G C_s k_t k_r k_{ms} \quad \left\{ \begin{array}{l} k_r = 0.897 \\ k_t = 1.0 \\ k_{ms} = 1.0 \text{ (idler)} \\ C_L = 1.0 \text{ (bending)} \\ C_G = 1.0 \\ C_s = 0.8 \text{ (assumption)} \end{array} \right.$$

$S_n = 12.558$ ksi

Hence $\sigma_{max} = 12558 = 105.3134\, F_{t\,max}$ $\qquad S'_n = \frac{70}{4} = 17.5$ ksi

$$F_{t\,max} = \frac{12558}{105.3134} = 119.244 \text{ Pounds force}$$

$F_{t\,max} = 119.244$ lbf or 530.4237 N

$$Power_{max} = F_{t\,max} \times \dot{V} = \frac{119.244 \times 2 \times 1 \times 1000}{33000 \times 12}$$

$$\boxed{\dot{W}_{max} = 0.9459 \text{ hp}}$$

3- Gear surface analysis, done by Moaaz Ahmed

Gear surface analysis

Given that :

$F_{t} = 119.244$ lbf or 530.4227 $\quad b = 1$ inch $\quad d_p = 1.98$ inch

$W_{max} = 0.9459$ hp $= 31214.7$ ft.lb $\quad V = 261.77$ fpm

assume curve C for kv, $\quad K_v = \frac{50 + \sqrt{V}}{50} = 1.32$

$K_o = 1.25 \quad K_m = 1.3$

$I = \frac{\sin\phi \cos\phi}{2} \times \frac{R}{R+1} = 0.13 \qquad C_p = 0.564\sqrt{\frac{1}{\frac{1-0.3^2}{82\ ksi} + \frac{1-0.3^2}{82\ ksi}}} = 6.71\sqrt{psi}$

$R = \frac{9.24}{1.98} = 5$

surface fatigue σ_H :

$\sigma_H = C_P \sqrt{\frac{F_t}{b\, d_p\, I} K_v K_o K_m} = 212.06\sqrt{psi}$ psi

surface endurance strength :

$S_H = S_{fe}\, C_{Li}\, C_R \qquad C_R = 1 \qquad C_{Li} =$ assume $(10^{10}) = 0.72$

$S_{fe} =$ ~~8 Mpa~~ 1.16 ksi

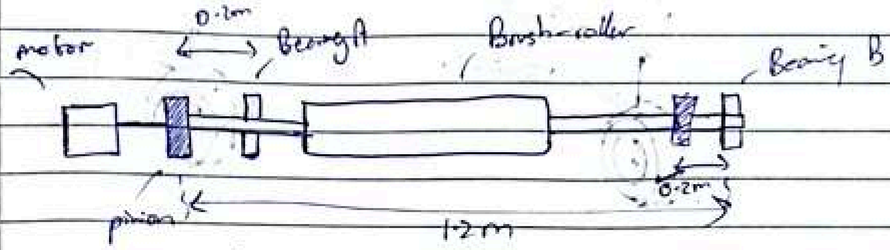
$S_H = 0.84$ ksi

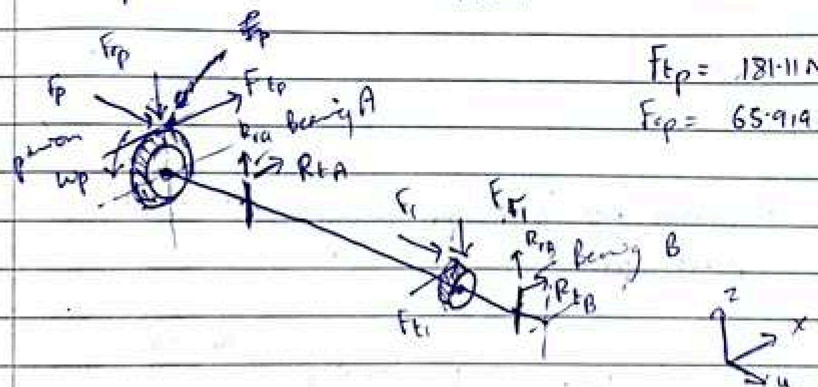
4-Bearing selection, done by Muhammad Arslan

Bearing Selection

4 rotating shafts

Shaft #1





$F_{tp} = 181.11N = F_{t_1}$

$F_{rp} = 65.919N = F_{r_1}$

$$\Sigma M_{A_z} = 0 = F_{tp} \times 0.2 - F_{t_1} \times 0.8 - R_{t_B} \times 1 = 0$$

$$R_{t_B} = -108.66 \text{ N}$$

$$\Sigma F_x = 0 = F_{tp} + F_{t_1} + R_{t_B} + R_{tA} = 0$$

$$R_{tA} = -253.56 \text{ N}$$

$$\Sigma M_{Ax} = F_{rp} \times 0.2 - F_{r_1} \times 0.8 + R_{r_B} \times 1 = 0$$

$$\boxed{R_{r_B} = 39.5514 \text{ N}}$$

5- shaft analysis, done by shammim

Railing rod stress analysis:

Assumptions:

$F_1 = 100N$

$F_2 = 100N$

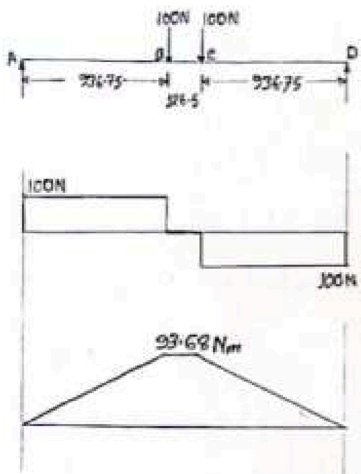
$L = 2000mm$

$d = 35mm$

Material: Steel

$E = 210$ GPa

$\sigma = 250$ MPa



$\circlearrowleft + M_A = 0$

$R_D \times L - F_2 \times 1063.25 - F_1 \times 936.75 = 0$

$\Rightarrow R_D \times 2000 - 100 \times 1063.25 - 100 \times 936.75 = 0$

$\Rightarrow R_D = 100$ N

$\uparrow + F_y = 0$

$R_A - F_1 - F_2 + R_D = 0$

$\Rightarrow R_A - 100 - 100 + 100 = 0$

$\Rightarrow R_A = 100$ N

$$\sigma_b = \frac{32M}{\pi d^3}$$

$$= \frac{32 \times 93.68}{\pi \times 0.035^3}$$

$$= 22.26 \text{ MPa}$$

$\tau = 0$

$$SF = \frac{\sigma_y}{\sigma_b}$$

$$= \frac{250}{22.26}$$

$$= 11.23$$

6- pump selection, done by Taraq

Engineering Analysis : Pump Selection

The pump is required to deliver water for cleaning the solar panels in the Rooftop Solar Panel Cleaning Device.

Flow rate (Q):

$$\left.\begin{array}{l} \text{Cleaning time, } t = 5 \text{ min} \\ \qquad = 300 \text{ s} \\ \text{Water required, } V = 10 \text{ liters} \\ \qquad = 0.01 \text{ m}^3 \end{array}\right] \text{per panel}$$

$$\therefore \text{Flow rate } Q = \frac{V}{t} = \frac{0.01}{300}$$

$$= 3.33 \times 10^{-5} \text{ m}^3/\text{s}$$

Static Head (H_s):

static head, $H_s = 1.5$ m

assume the water tank placed 1.5 m below the solar panel

Friction losses (H_f):

friction factor, $f = 0.02$

pipe length, $L = 8$

pipe diameter, $D = 0.01$ m

fluid velocity, v

acceleration due to gravity, $g = 9.81 \text{ m/s}^2$

So, fluid velocity, $v = \frac{Q}{A} = \frac{3.33 \times 10^{-5}}{\pi (0.01/2)^2}$

$= 0.42$ m/s

$\therefore$ Friction losses, $H_f = f \cdot \frac{L}{D} \cdot \frac{v^2}{2g}$

$= 0.02 \ \frac{8}{0.01} \cdot \frac{(0.42)^2}{2 \times 9.81}$

$= 0.14$ m

Velocity Head (H_v):

velocity head, $H_v = \frac{v^2}{2g} = \frac{(0.42)^2}{2 \times 9.81}$

$= 0.009$ m

$\therefore$ Total Dynamic Head, $TDH = H_s + H_f + H_v$

$= 1.5 + 0.14 + 0.009$

$= 1.649$ m

$\therefore$ Pump Power, $P = \frac{Q \cdot \rho \cdot g \cdot TDH}{\eta}$

$= \frac{3.33 \times 10^{-5} \times 1000 \times 9.81 \times 1.649}{0.7}$

$= 0.77$ watt

Fluid density, $\rho = 1000$ kg/m³

Pump efficiency, $\eta = 70\%$

Pump selection:

Based on the calculations:

Flow Rate, $Q = 3.33 \times 10^{-5}\ m^3/s \simeq 2\ L/min$

Total Dynamic Head = 1.649 m

Required pump power = 0.77 W

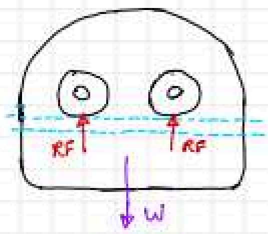
We can select a smal centrifugal pump or diaphragm pump with flow rate of 2-5 L/min and Head is 2-5 m.

SHAFT ANALYSIS - ROLLER SHAFT - AHMED MOHAMEDALI

Engineering Analysis: Roller shafts

Beam Analysis

The rollers are the main components carrying the entire weight of the device on the railings.



$\uparrow \Sigma F_y = 0$

$2RF - W = 0$

$\therefore\ 2RF = W$, where W is the maximum weight of one unit at either side.

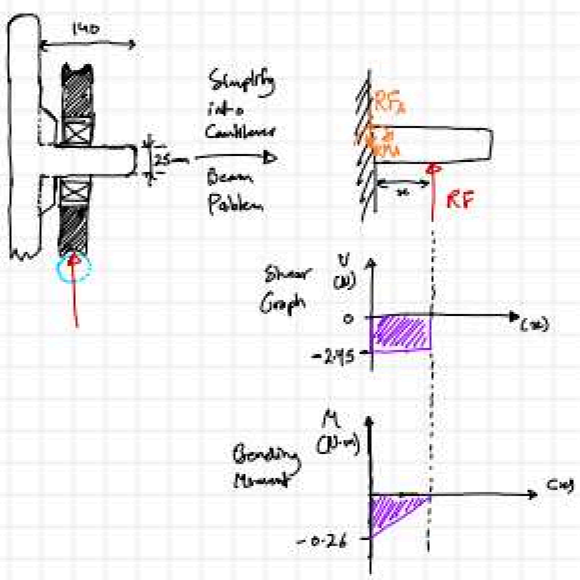
The estimated weight of the device unit is assumed to be 0.5 kg. This considers the metal gears and the powerful torque motor.

Hence:

$2RF = 0.5(9.81)$

$RF = \frac{0.5(9.81)}{2}$

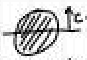
$RF = 2.4525\ N$ #



x is measured at 107 mm from the fixed end.

$RM_x = RF \times x$
$= 2.4525 \times 107 \times 10^{-3}$
$= 0.2624\ N{\cdot}m$

~~Shear~~ Shear stress:



$\tau = \dfrac{VQ}{It}$

$Q = \frac{2}{3}c^3$

$= \frac{2}{3}(12.5\times10^{-3})^3$

$= 1.3021\times10^{-6}$

$D = 25$ mm

$c = r = \frac{25}{2} = 12.5$ mm

$I = \frac{\pi}{4}c^4$

$= \frac{\pi}{4}(12.5\times10^{-3})^4$

$= 1.9175\times10^{-8}\ m^4$

$t = D = 25\times10^{-3}$ m

$\therefore\ \tau = \dfrac{(2.4525)(1.3021\times10^{-6})}{(1.9175\times10^{-8})(25\times10^{-3})}$

$= 6.6616$ kPa

→ Allowable shear stress of HDPE (High Density Polyethylene)

$\tau_{allow} = 80$ kPa

$\therefore$ Safety factor: $S.F. = \dfrac{\tau_{allow}}{\tau}$

$= \dfrac{80\times10^3}{6.6616\times10^3}$

$= 12$ #

S.F higher than 2, hence safe from failure due to shear stress.

~~Be~~ Bending Stress:

$\sigma = \dfrac{My}{I}$

$y = r = 12.5\times10^{-3}$ m

$I = 1.9175\times10^{-8}\ m^4$

$\sigma = \dfrac{(0.2624)(12.5\times10^{-3})}{1.9175\times10^{-8}}$

$= 171.056$ kPa

Allowable yield tensile strength of HDPE: $\sigma_{allow} = 15$ MPa

$S.F. = \dfrac{15\times10^6}{171.056\times10^3}$

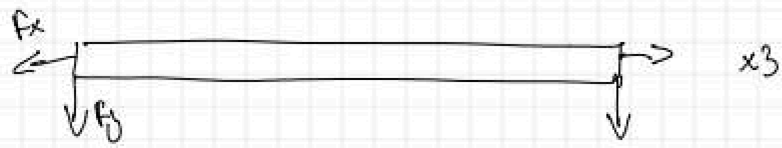
$= 87.69 \approx 87$

S.F > 2 hence safe from bending stress.

SHAFT ANALYSIS - MIDDLE SHAFT - MAZEN OMAR

$l = 1.098\ m$ weight of housing $= 0.5 kg$

3 beam



$F_y = F_{gravity} = 0.5 \times 9.81 = 4.905\ N$

$F_{total} = 2 \cdot F_{gravity} = 9.81\ N$

force per beam $F = \frac{9.81}{3} = 3.27\ N$

assume $F_x = 30\ N$

$b = 10mm$ $\sigma_{yield} = 250mpa$ (aluminume)

$h = 20mm$

$$F_{result} = \sqrt{3.27^2 + \left(\frac{30}{3}\right)^2} = 10.53\ N$$

$$M_y = \frac{F.L}{4} = \frac{3.27 \times 1.096}{4} = 0.896\ Nm$$

$$M_x = \frac{30 \times 1.098}{12} = 2.745\ Nm$$

$$M_{total} = \sqrt{2.745^2 + 0.896^2} = 2.89\ Nm$$

$$I = \frac{0.01 \times 0.02^3}{12} = 6.67 \times 10^{-9}\ m^4$$

$$C = \frac{0.02}{2} = 0.01\,m$$

$$\frac{M_{tota}\,C}{I} = \sigma_{max} = \frac{6 \times 2.89}{0.01 \times 0.02^2} = 4.335\,mpa$$

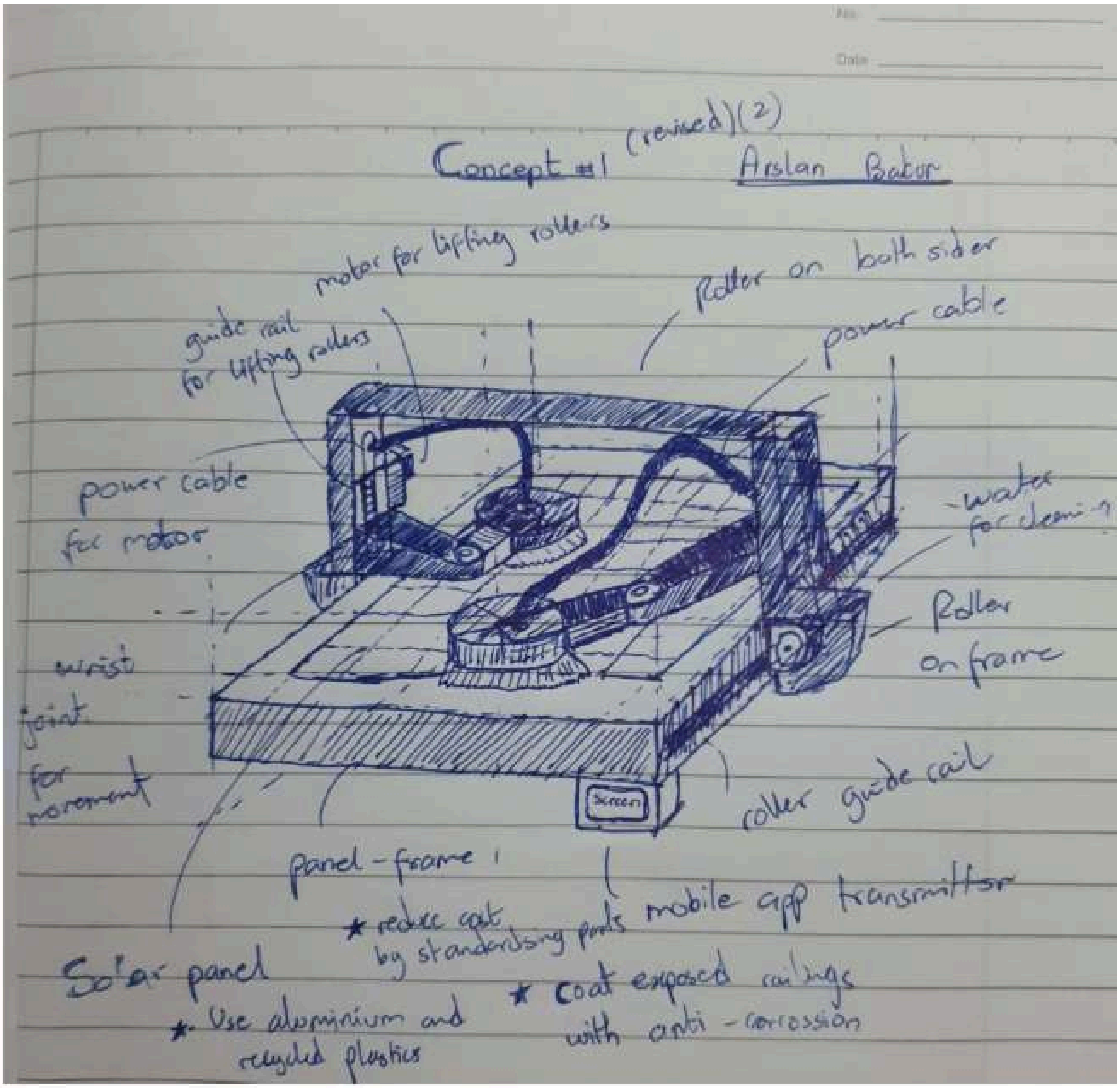
$$\frac{\sigma_{yeild}}{\sigma_{max}} = SF = \frac{250}{4.335} = 57.66 \quad (safe > 1)$$

Can support without failing

Appendix - B: Padlet Link for Brainstorming

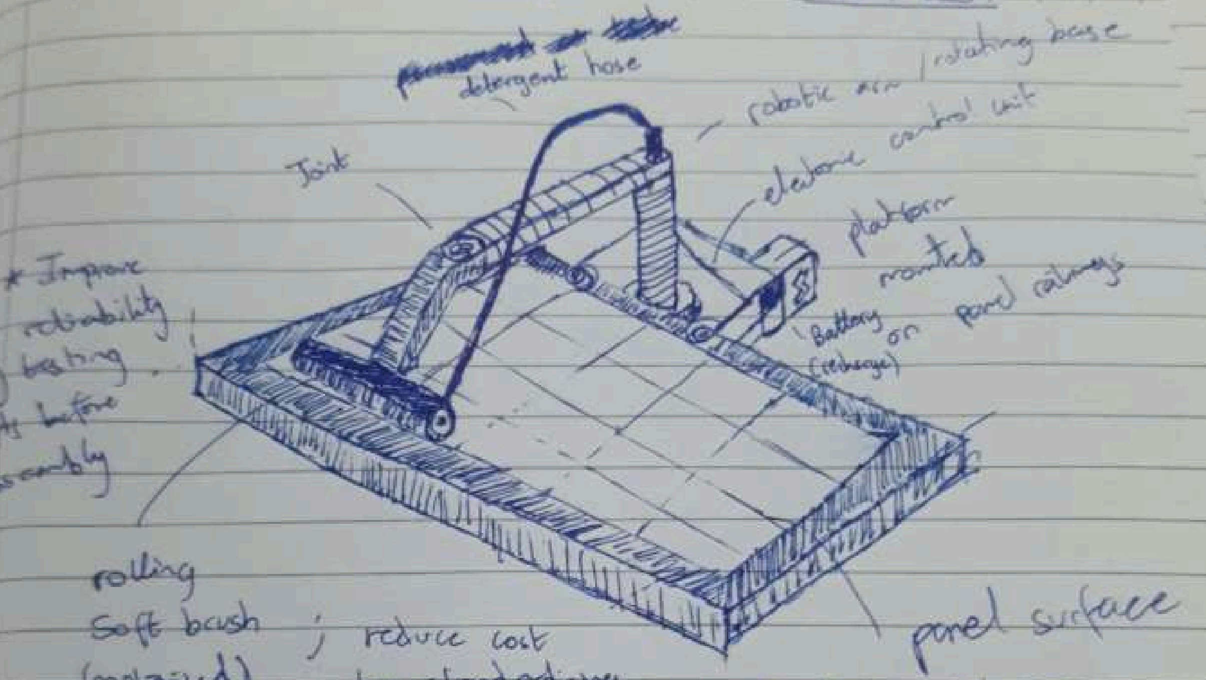
https://padlet.com/ahmedp0/concept-brainstorming-a7iuu08zcudzq3d4

Appendix- C Revised Concept Drawings



Concept #2 (revised) (2)

Arslan Babur



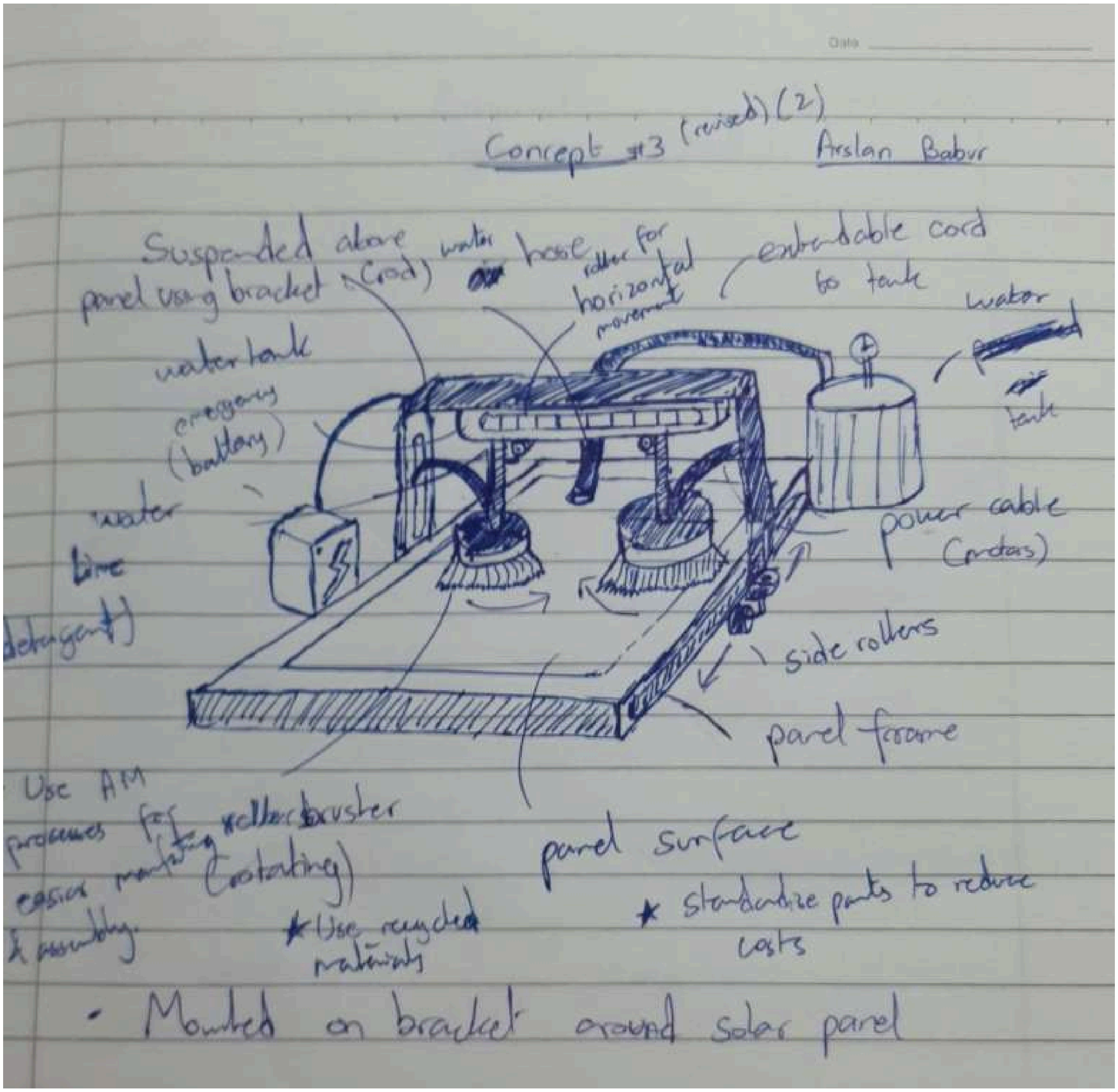
* Improve reliability by testing parts before assembly

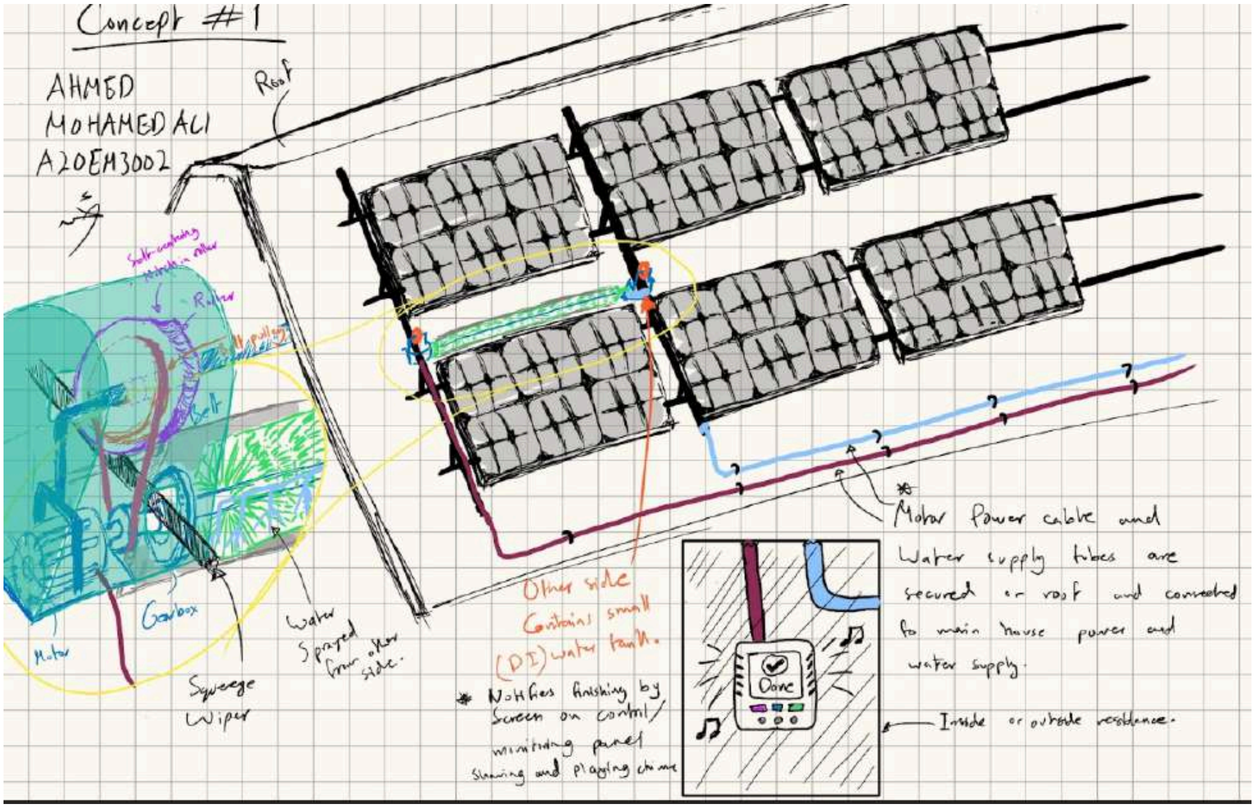
; reduce cost by standardising parts

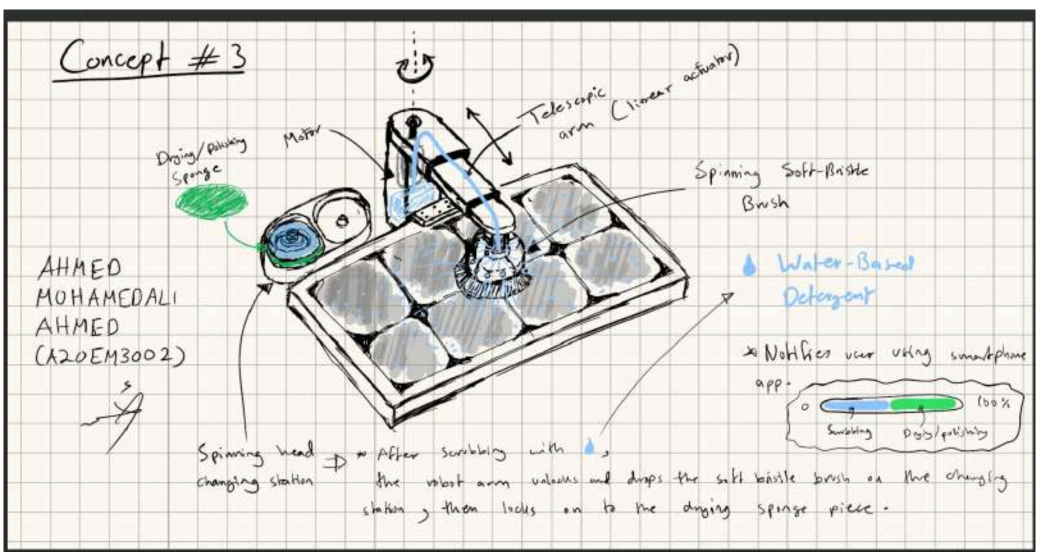
; Make robot arm frame from recycled plastic and alloys.

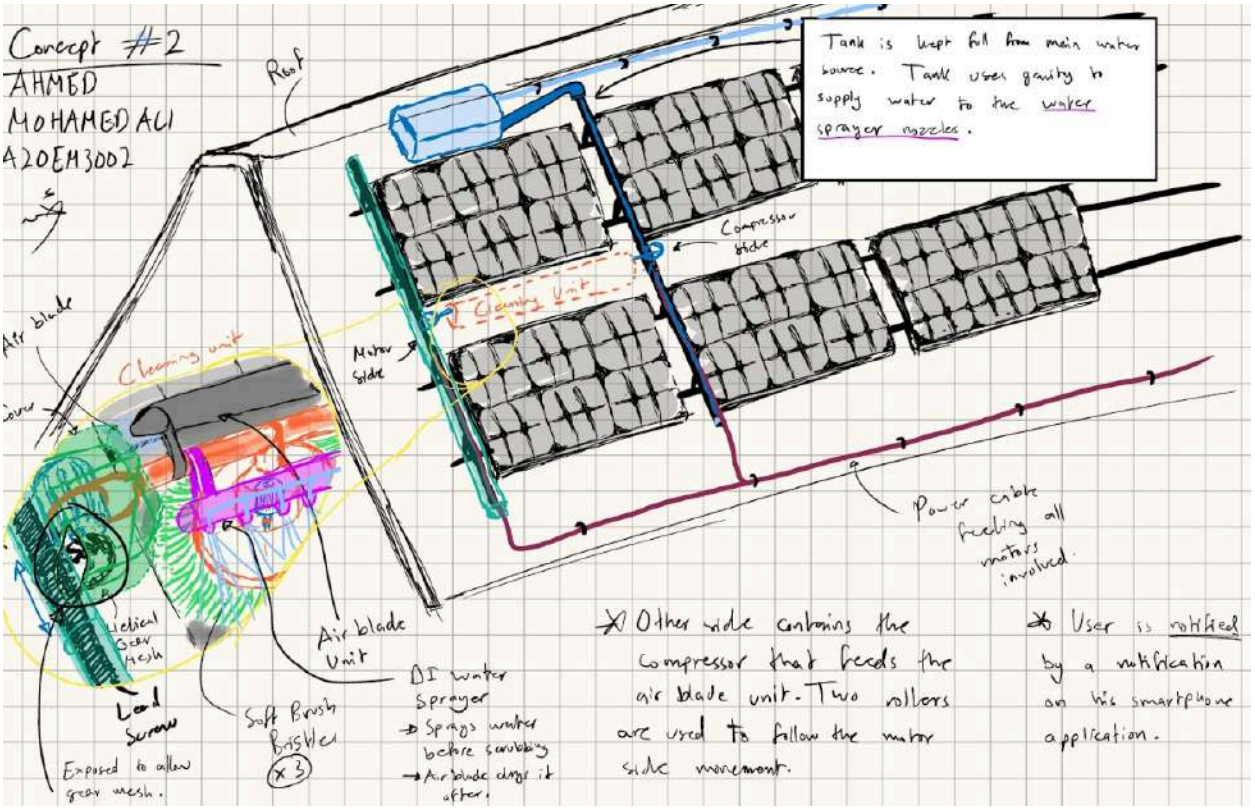
- Device is mounted on solar panel's railings

- Using a robotic arm with 360° base rotation, and a wrist joint with 180° rotation, which-

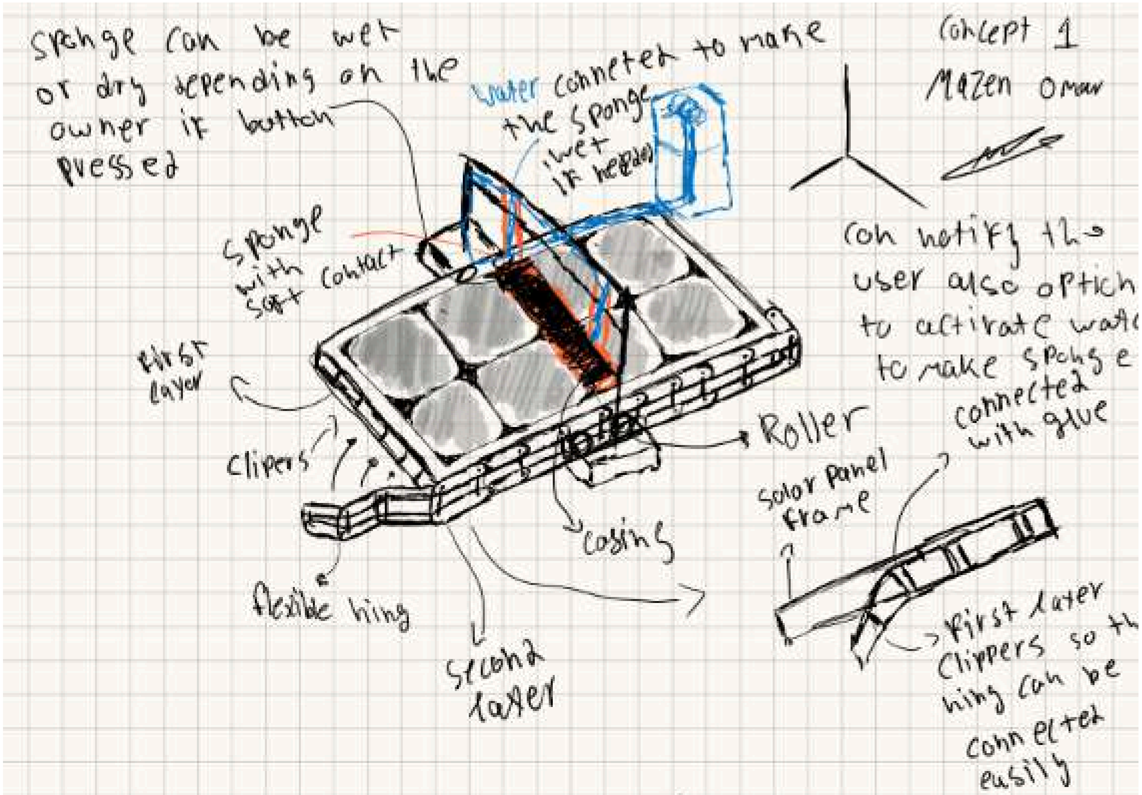

Date
Concept #3 (revised) (2)
Arslan Babur
Suspended above panel using bracket (rod)
water hose
roller for horizontal movement
extendable cord to tank
water tank
water tank
emergency (battery)
water line
detergent)
power cable (motors)
side rollers
panel frame
Use AM processes for easier manufacturing & assembly
roller brushes (rotating)
panel surface
★ Use recycled materials
★ standardize parts to reduce costs
• Mounted on bracket around solar panel

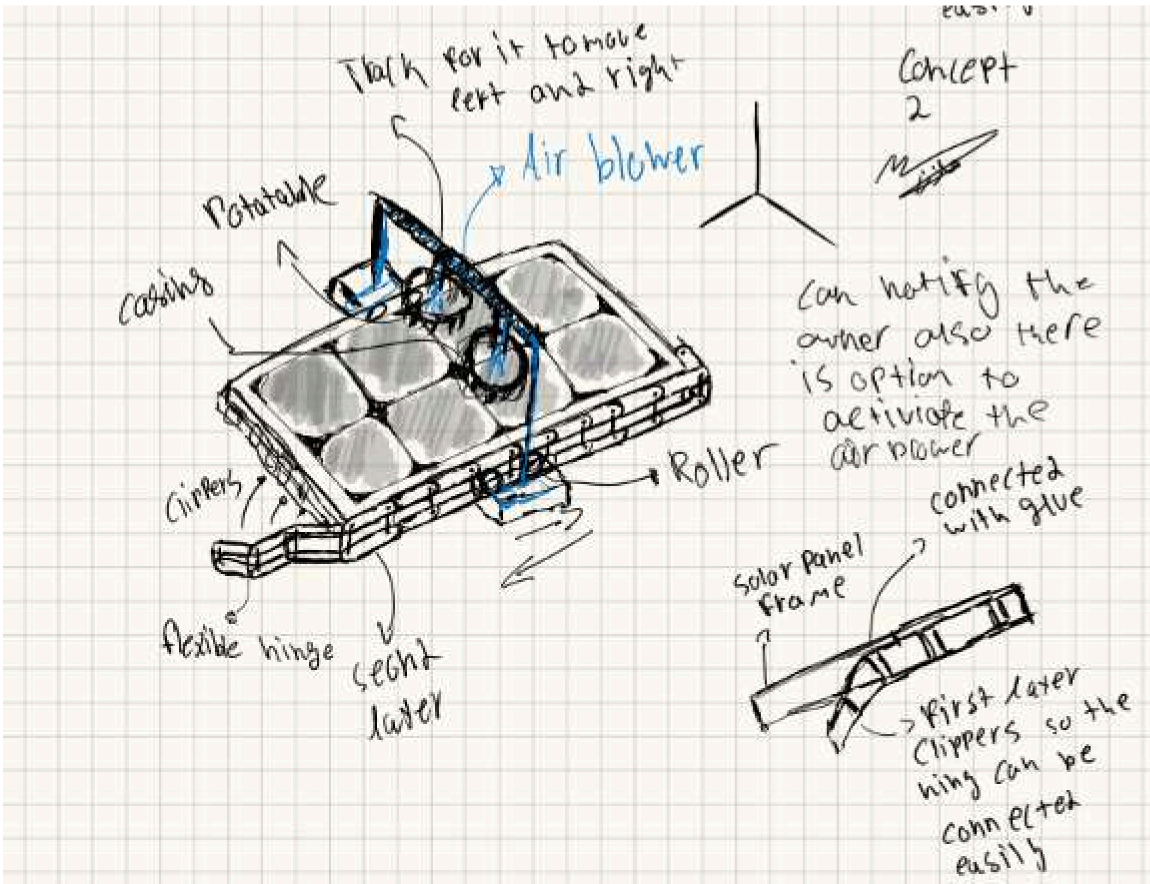

Concept #1
AHMED
MOHAMED ALI
A20EM3002
Roof
Belt
Gearbox
Motor
Water Sprayed from other side.
Squeege Wiper
Other side Contains small (DI) water tank.
* Notifies finishing by Screen on control/monitoring panel Showing and playing chime
Done
* Motor Power cable and Water supply tubes are secured on roof and connected to main house power and water supply.
Inside or outside residence.

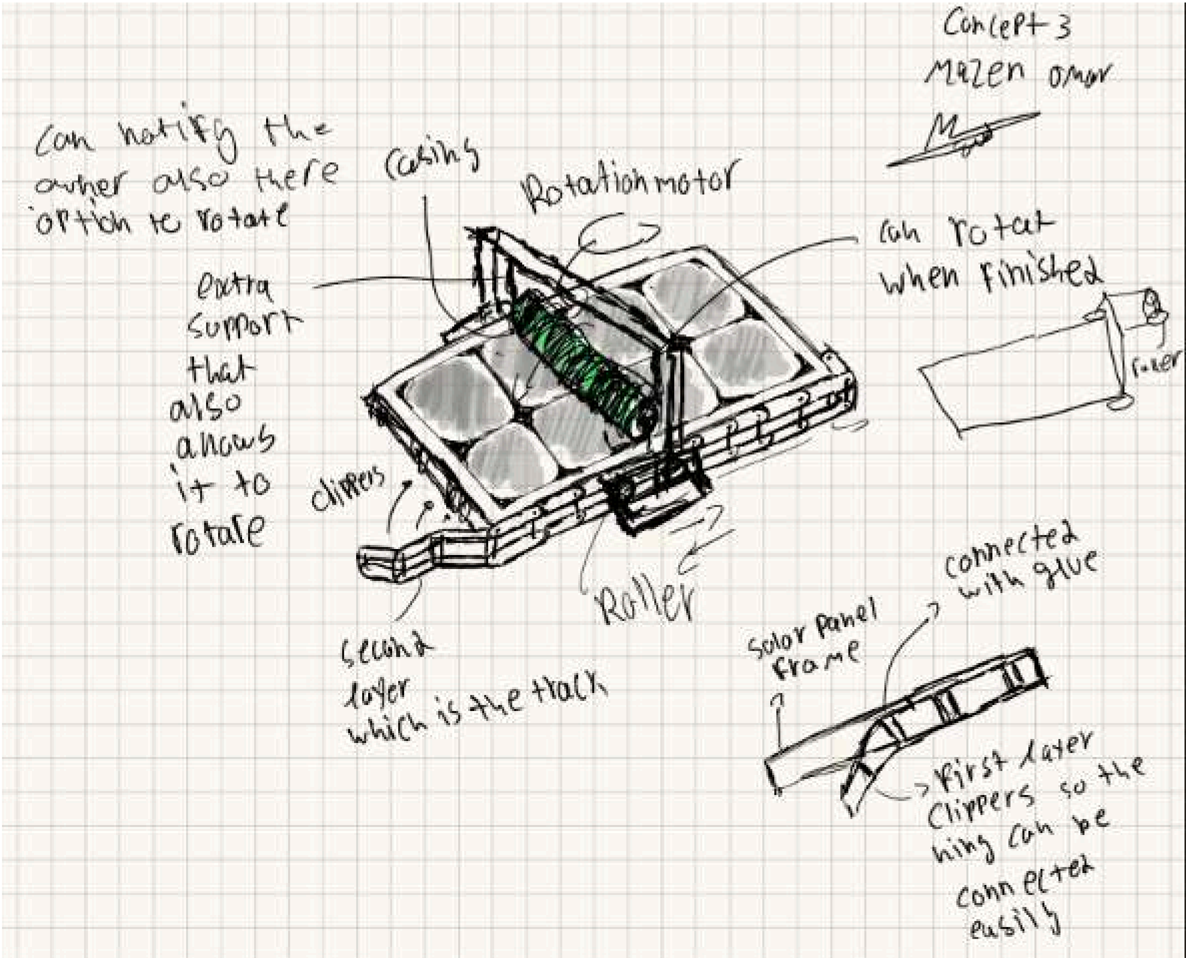

Concept #3
Telescopic arm (linear actuator)
Motor
Drying/polishing Sponge
Spinning Soft-Bristle Brush
Water-Based Detergent
AHMED
MOHAMEDALI
AHMED
(A20EM3002)
* Notifies user using smartphone app.
0
100%
Scrubbing
Drying/polishing
Spinning head changing station
* After Scrubbing with , the robot arm unlocks and drops the soft bristle brush on the changing station, then locks on to the drying sponge piece.



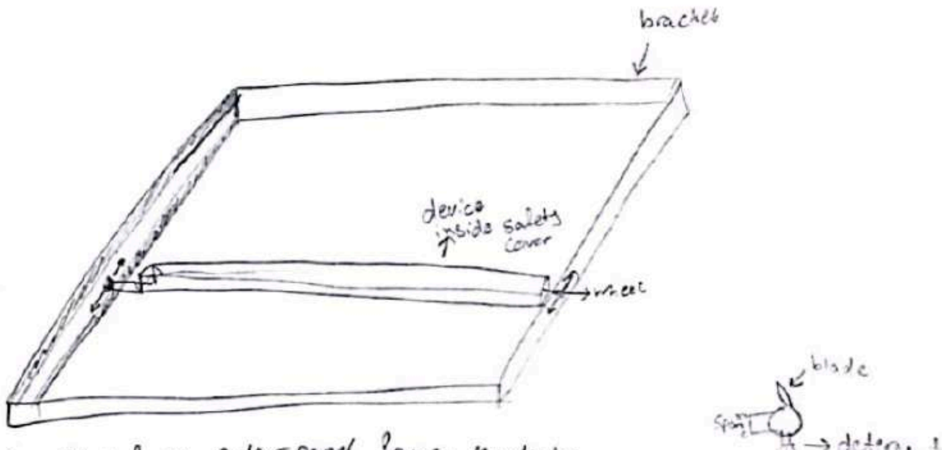
Concept #2
AHMED
MOHAMED ALI
A20EM3002
Roof
Tank is kept full from main water source. Tank uses gravity to supply water to the water sprayer nozzles.
Compressor side
Cleaning Unit
Motor side
Air blade
Cover
Cleaning unit
Helical Gear Mesh
Lead Screw
Exposed to allow gear mesh.
Soft Brush Bristles (x3)
Air blade Unit
DI water Sprayer
→ Sprays water before scrubbing
→ Air blade drys it after.
Power cable feeding all motors involved.
* Other side contains the compressor that feeds the air blade unit. Two rollers are used to follow the motor side movement.
* User is notified by a notification on his smartphone application.


Sponge can be wet or dry depending on the owner if button pressed
water conneted to make the sponge wet if needed
Concept 1
Mazen Omar
Sponge with soft contact
can notify the user also option to activate water to make sponge
First layer
Clipers
Roller
connected with glue
Solar panel frame
casing
flexible hing
Second layer
First layer clippers so the hing can be connected easily


Track for it to move left and right
Concept 2
Air blower
Rotatable
casing
Can notify the owner also there is option to activate the air blower
Roller
Clippers
connected with glue
Solar Panel Frame
flexible hinge
second layer
first layer
Clippers so the hing can be connected easily


Concept 3
Mazen Omar
Can notify the owner also there option to rotate
Casing
Rotation motor
Can rotat when finished
extra support that also allows it to rotate
Power
clippers
Roller
second layer which is the track
connected with glue
Solar Panel Frame
First layer Clippers so the hing can be connected easily

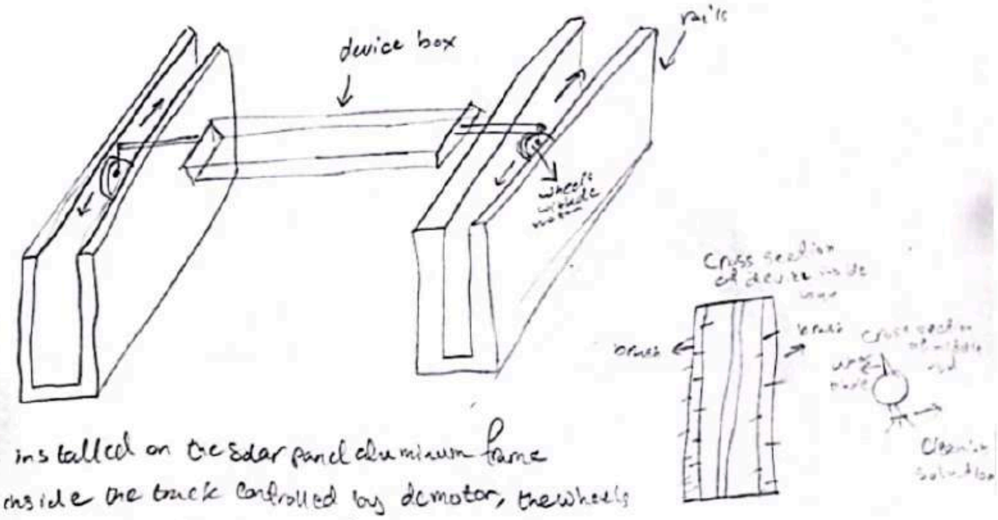
Concept 1 V2



bracket is placed on solar panel frame, the device
is a rod that has all 3 functions and rotates between them
the device is placed inside a rectangular aluminium box for environmental conditions cover
the box is connected to dc motor that controls wheels that move in the track

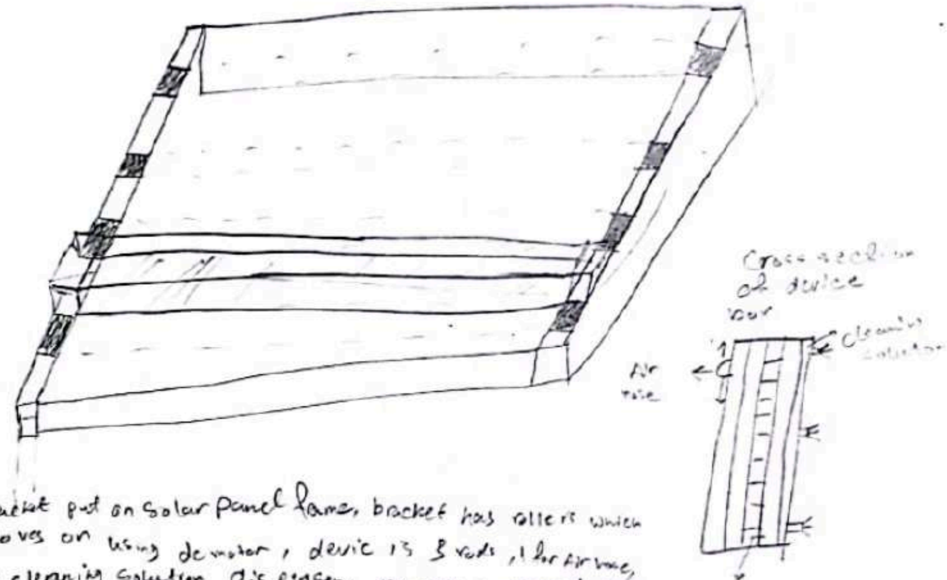
User is notified using a control box.

Concept 2 V2



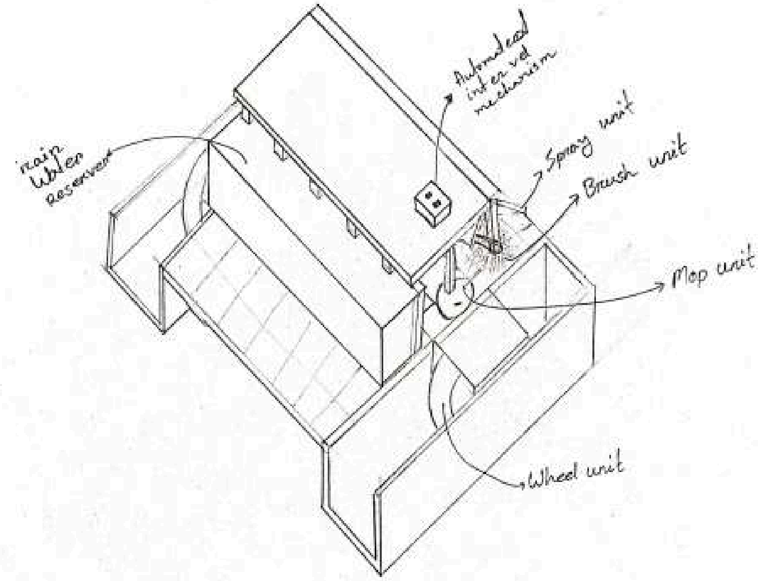
tracks are installed on the solar panel aluminum frame rollers move inside the track controlled by dc motor, the wheels are connected to the device which is placed inside a cover box to protect from environment conditions, device has three rods (2 rolling brushes and a middle rod that rotates between viper blade and cleaning source, user notified on a control unit.

Concept 3 V2



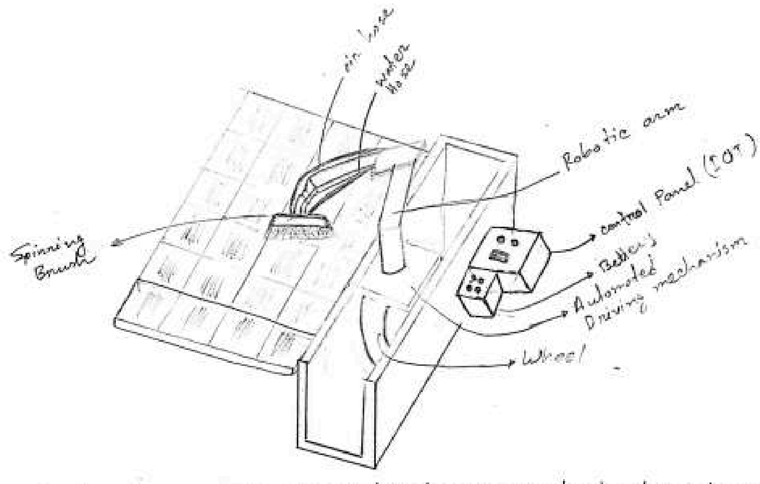
device bracket put on Solar Panel frame, bracket has rollers which the device moves on using dc motor, devic is 3 rods, 1 for Air wave, 1 sponge, 1 cleaning Solution dispencer, the rods are covered with

Concept-1



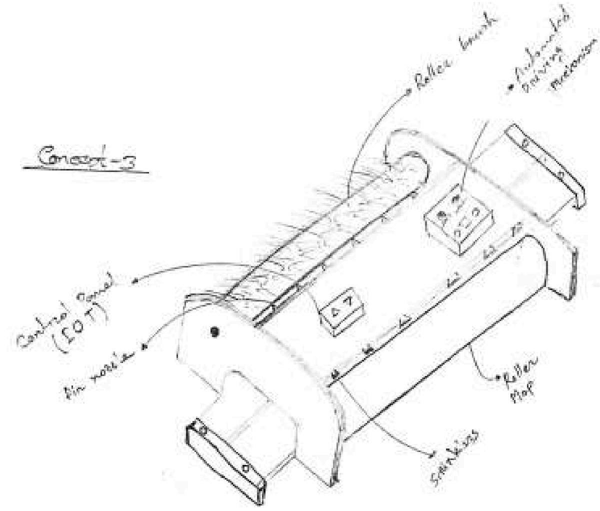
The solar panel cleaning device operates after certain time interval on the solar panel. The cleaning device includes a fluid sprayer, brush and mop unit. The fluid spray unit applies cleaning solution or water, the rotating brush removes dust, and the mop cleans and dries the solar panel surface.

Concept:-2



motorized wheel system attached to the frame of the solar panel. that allows the cleaning device to move smoothly
om one end to anothere end of the panel. A rotating arm extends over the solar panel that moves from one side to the
er side while cleaning.

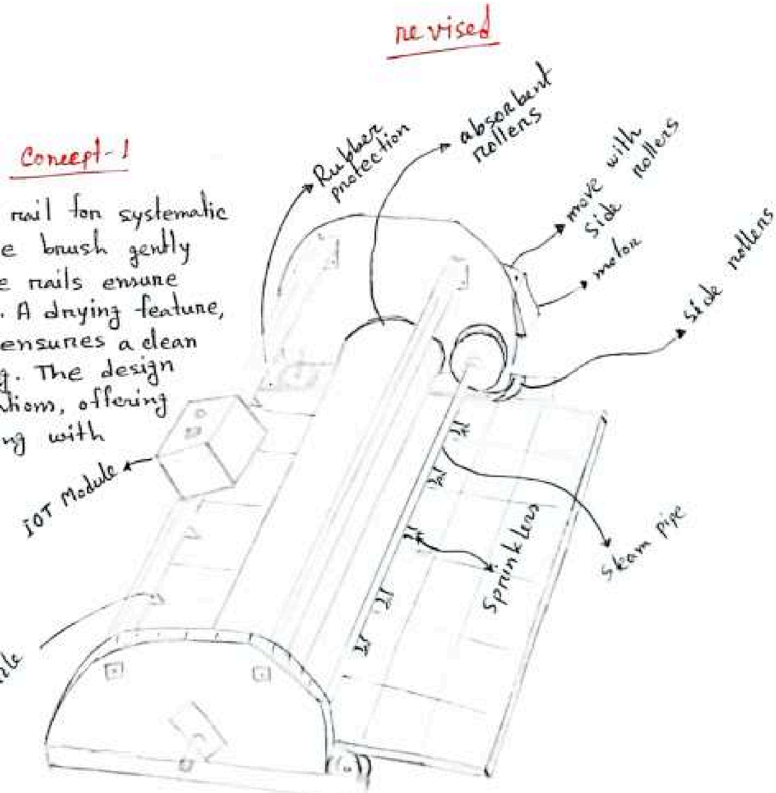
Concept-3

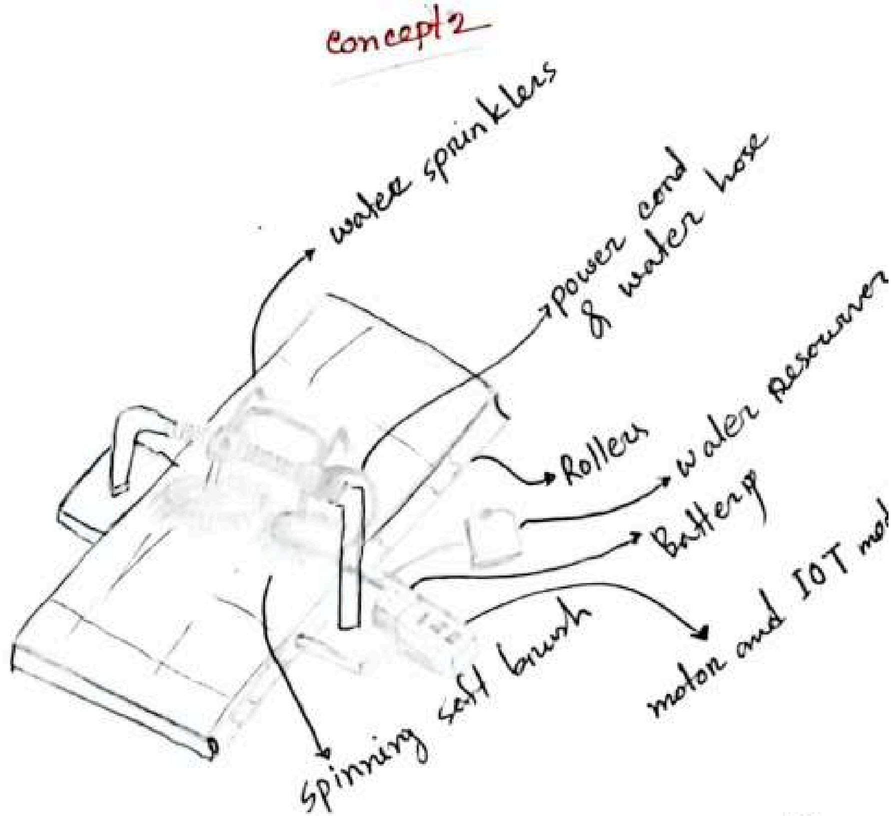


This solar panel cleaning device uses a movable frame mounted on the photovoltaic panel, which travels horizontally along the panel's surface. The cleaning device attached to the frame includes various cleaning tools such as brushes, cloths, nozzle for spraying water, designed to clean the panel effectively. The cleaning body can incorporate suction or ventilation mechanisms for removing dust and debris from the panel's surface.

Concept-1

This concept uses a rolling soft brush mounted on dual rail for systematic cleaning of solar panels. The brush gently cleans the surface while the rails ensure stability and uniform motion. A drying feature, such as steam or hot air, ensures a clean and dry finish after washing. The design is effective for large installations, offering consistent and through cleaning with enhanced stability.

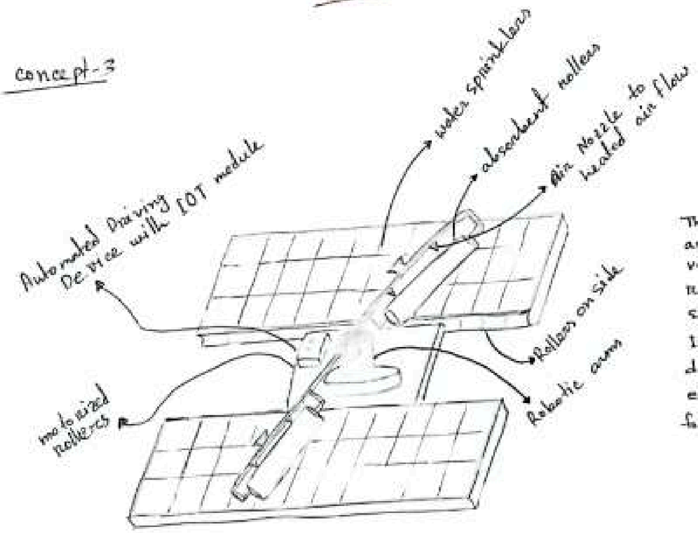




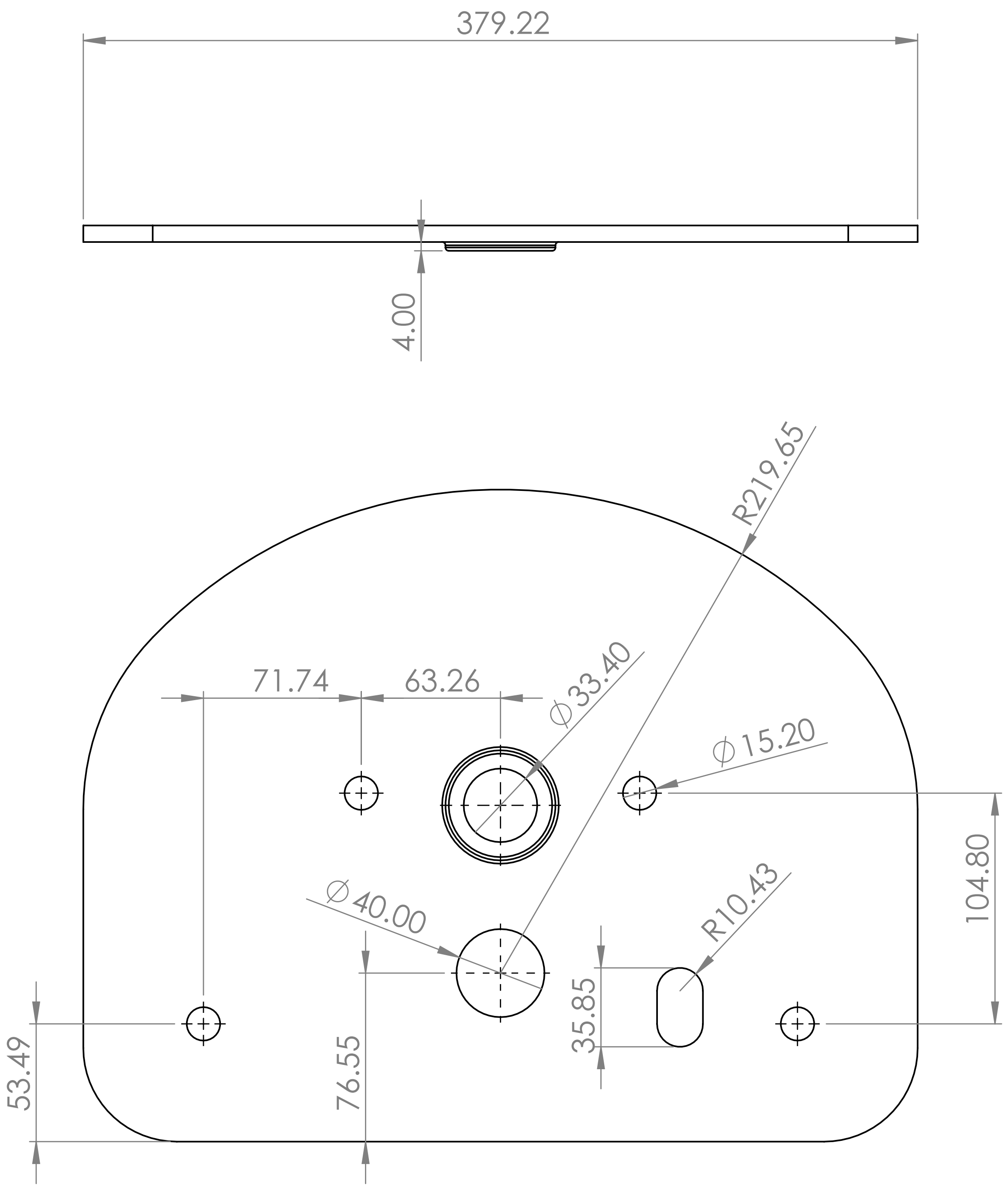
This concept combines rollers for mobility, spinning soft brushes for scrubbing, and integrated sprinklers for wet cleaning. The spinning brushes efficiently remove dirt, while the sprinklers provide water for cleaning. The rollers ensure smooth navigation, making this compact design effective for smaller or modular solar panel systems. It's simplicity and portability suit a variety of cleaning needs.

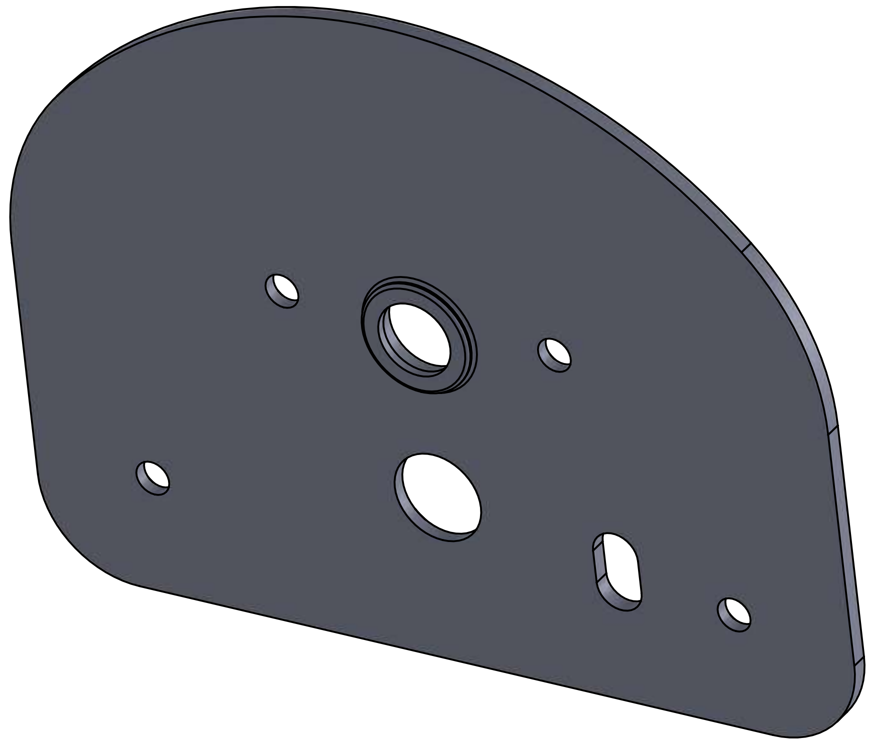
Revised

concept-3



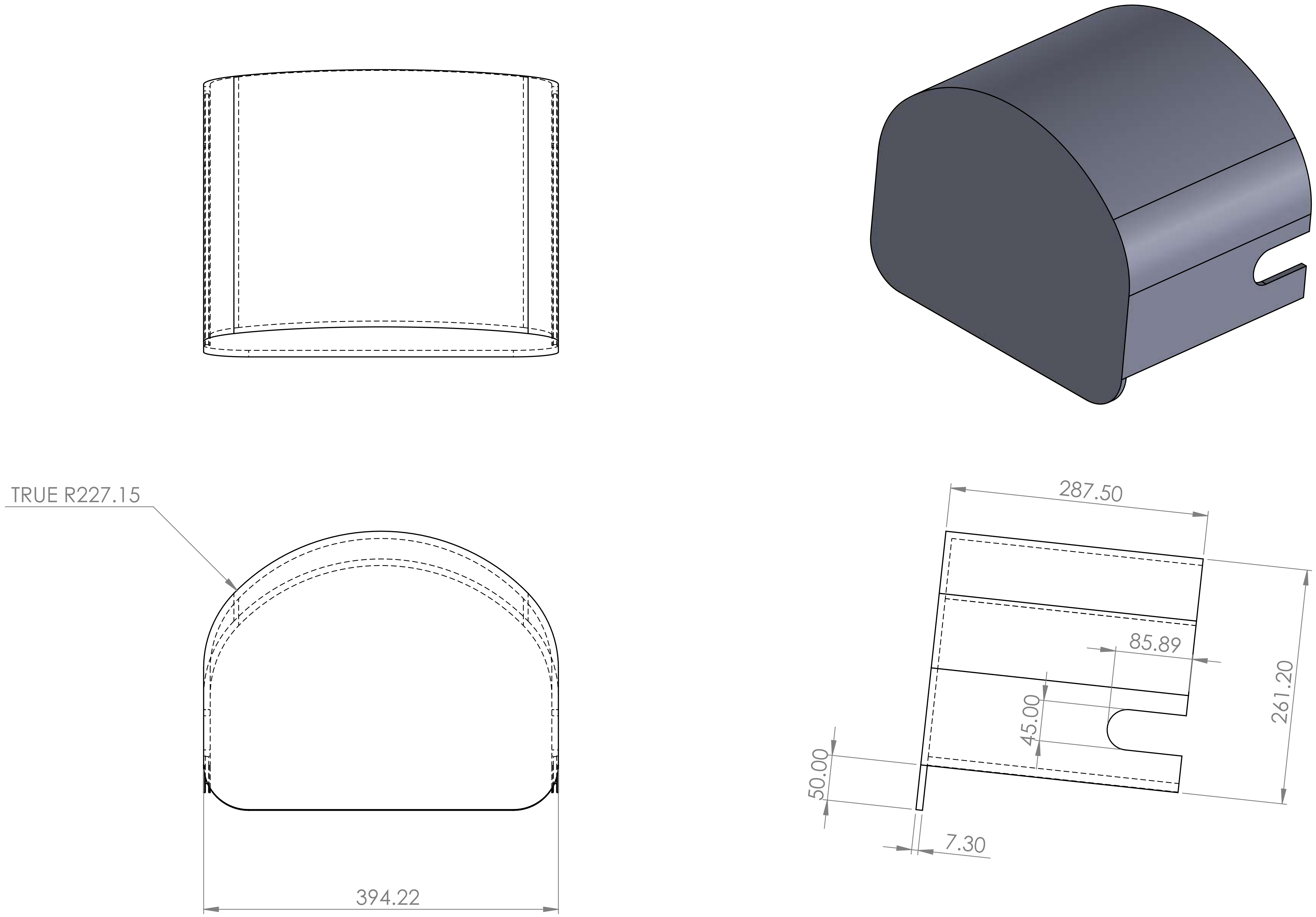
This concept features a flexible robotic arm for adaptable cleaning of panels in various arrangements. The arm holds a rolling soft brush for surface cleaning, supported by side rollers for stability. Integrated water sprinklers assist with debris removal, enhancing overall cleaning efficiency. It's adaptability makes it ideal for panels in complex or irregular configuratio



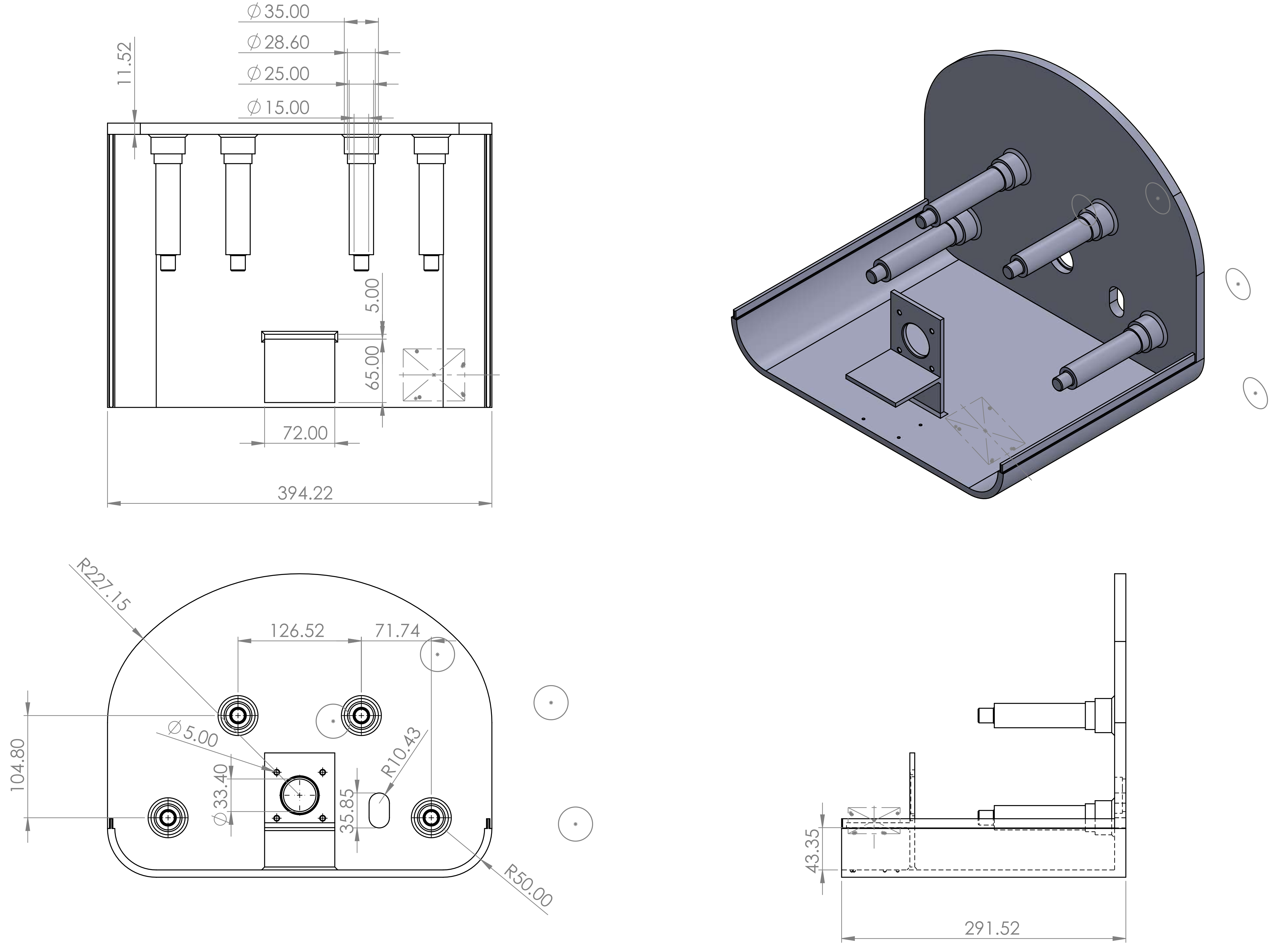


UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING

TITLE: Gearbox Support Plate	COURSE: System Design	DATE: 07 Feb 25	
	SECTION: 04	SCALE: 1:3	



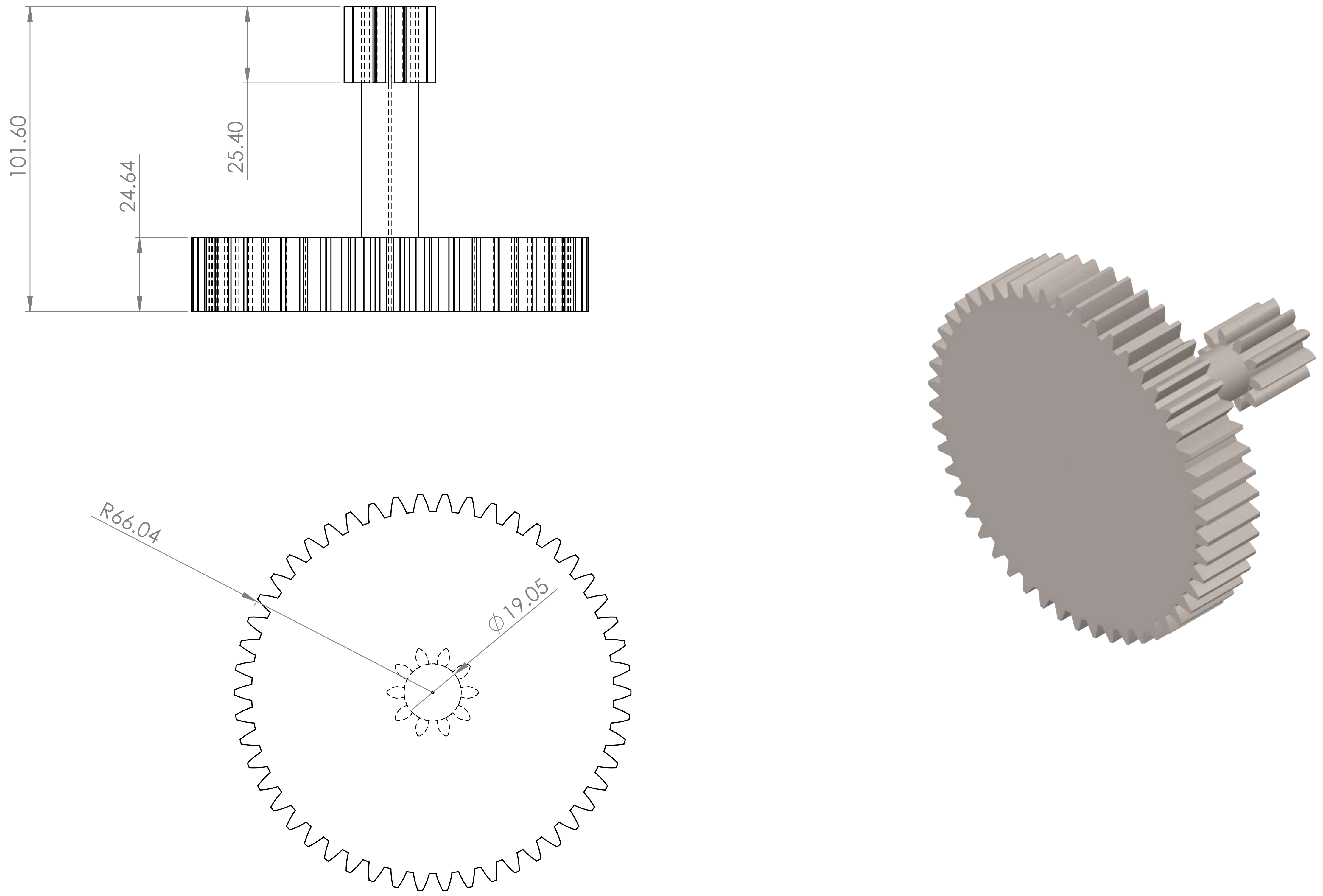
UTM UNIVERSITI TEKNOLOGI MALAYSIA	UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: Housing Cover	COURSE: System Design SECTION: 04	DATE: 07 Feb 25 SCALE: 1:5



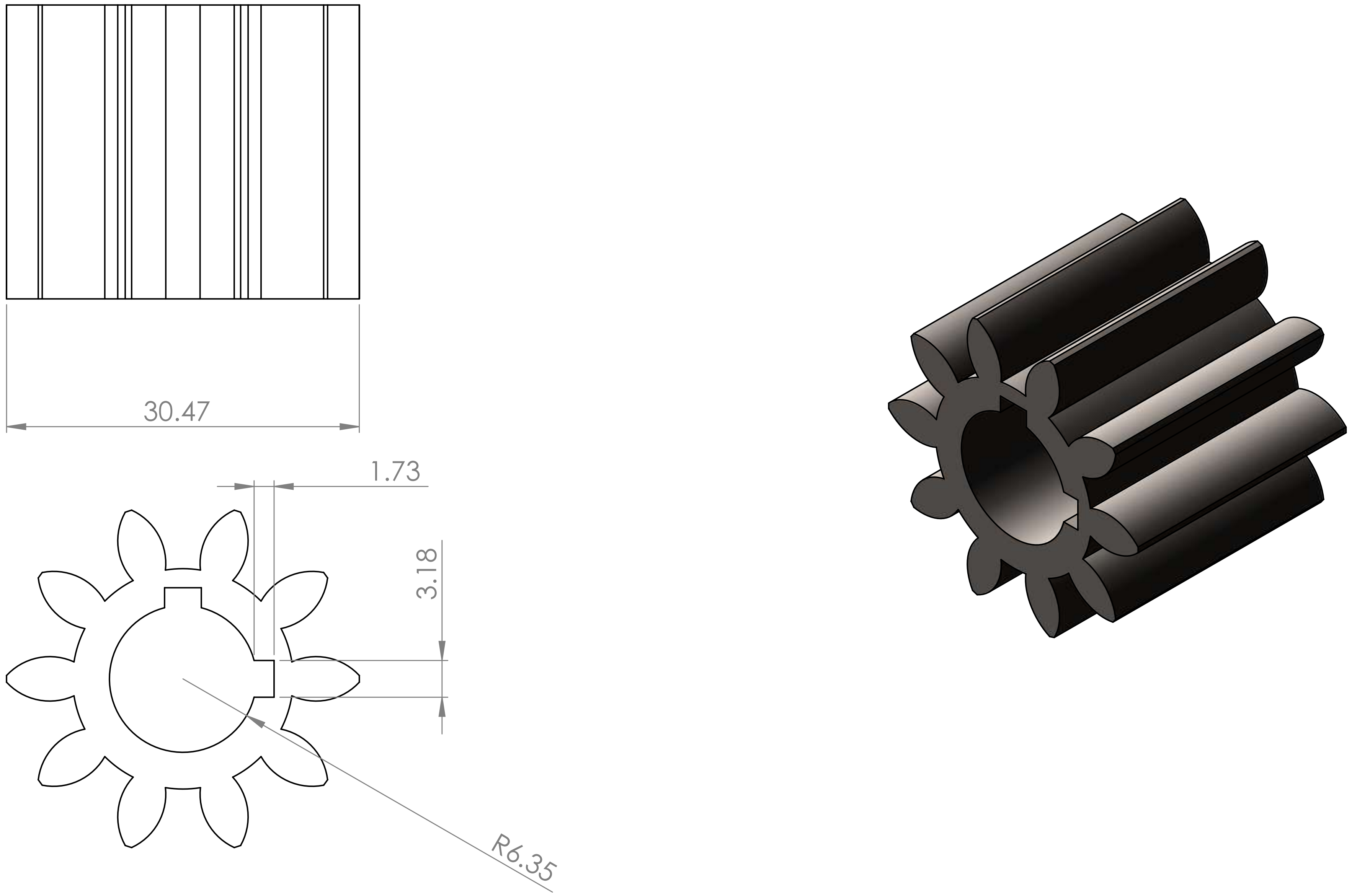
UNIVERSITI TEKNOLOGI MALAYSIA

SCHOOL OF MECHANICAL ENGINEERING

TITLE: Housing Base	COURSE: System Design	DATE:	07 Feb 25
	SECTION: 04	SCALE:	1:4

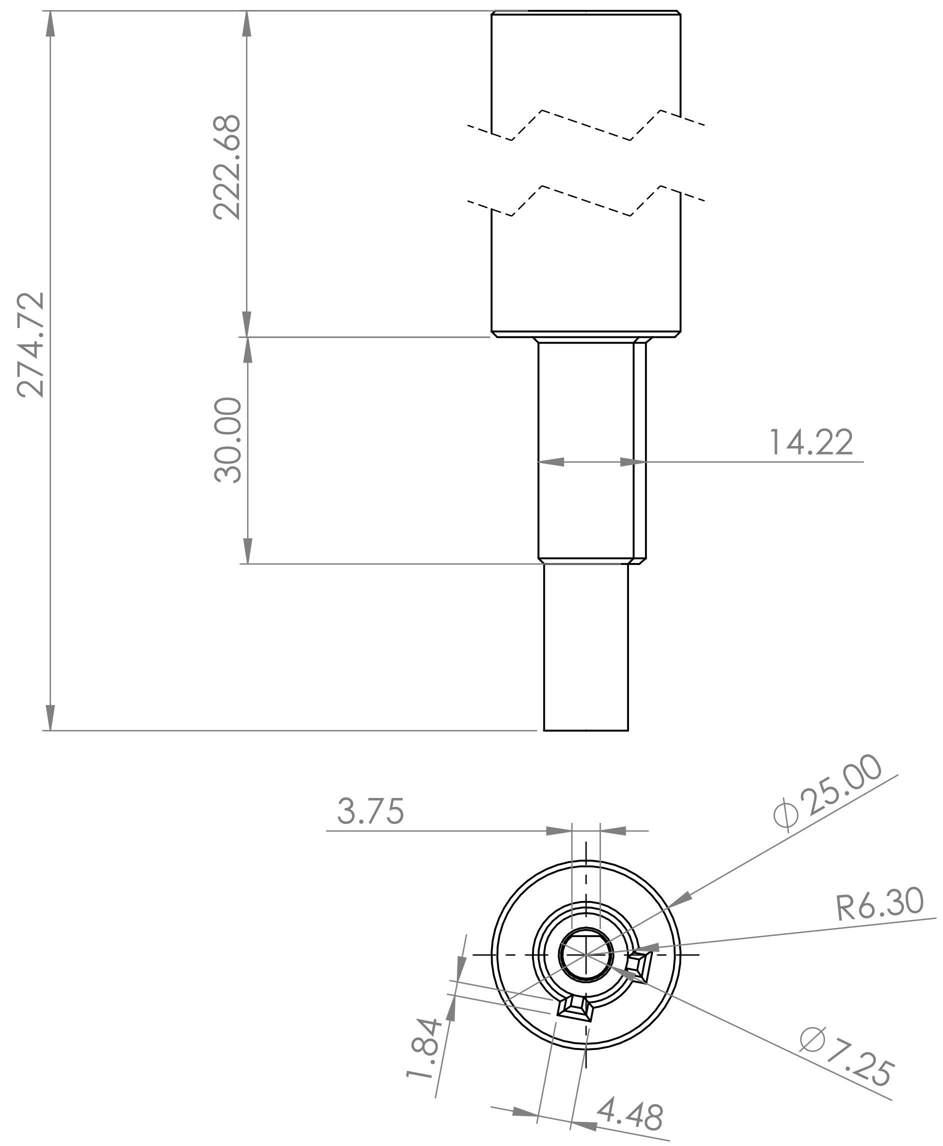


UTM UNIVERSITI TEKNOLOGI MALAYSIA UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: Idler Gear	COURSE: System Design SECTION: 04	DATE: 07 Feb 25 SCALE: 1:1.5



UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING

TITLE:	Input Pinion
COURSE:	System Design
SECTION:	04
DATE:	07 Feb 25
SCALE:	2:1

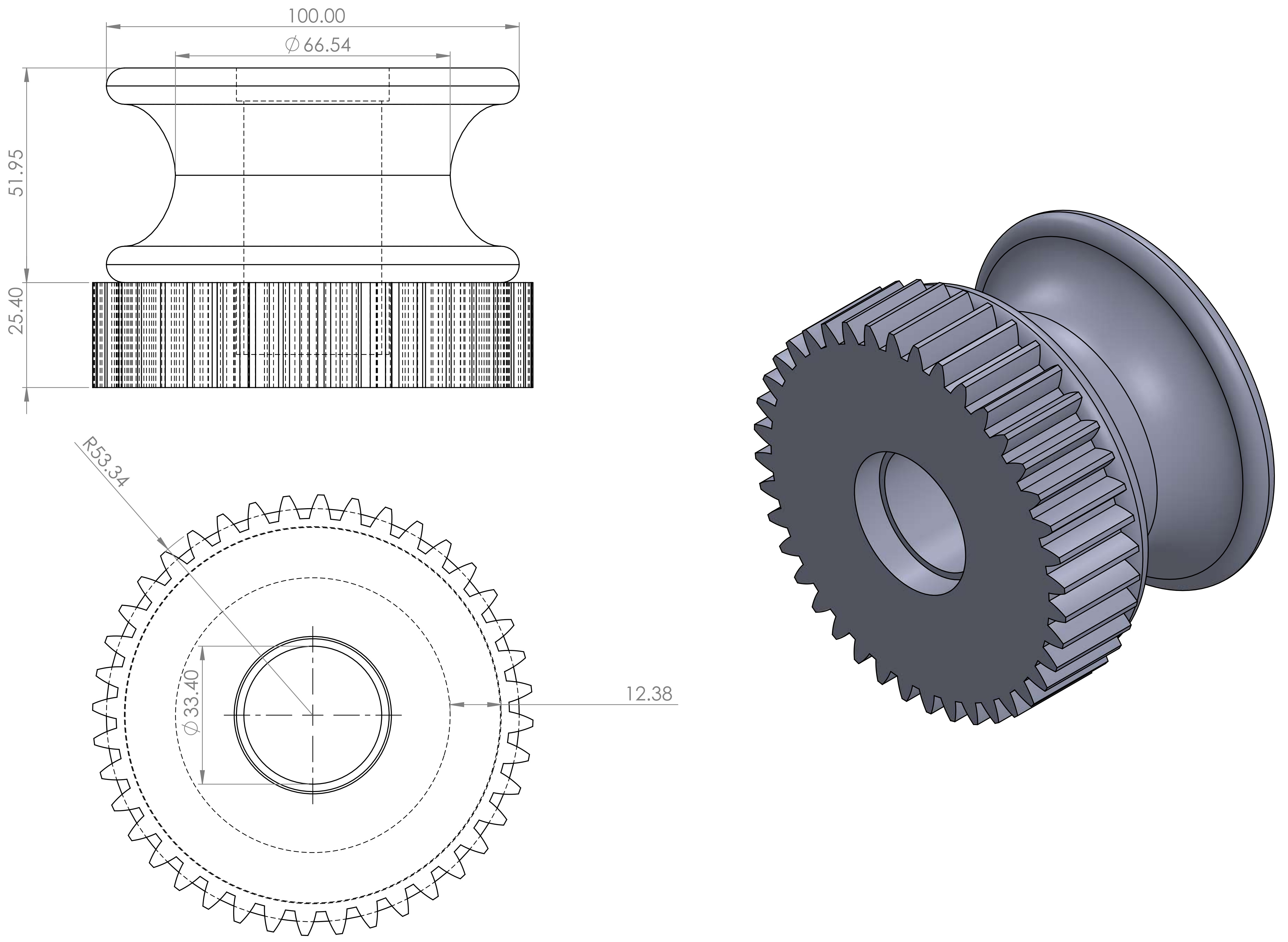


UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING

TITLE: Input Shaft

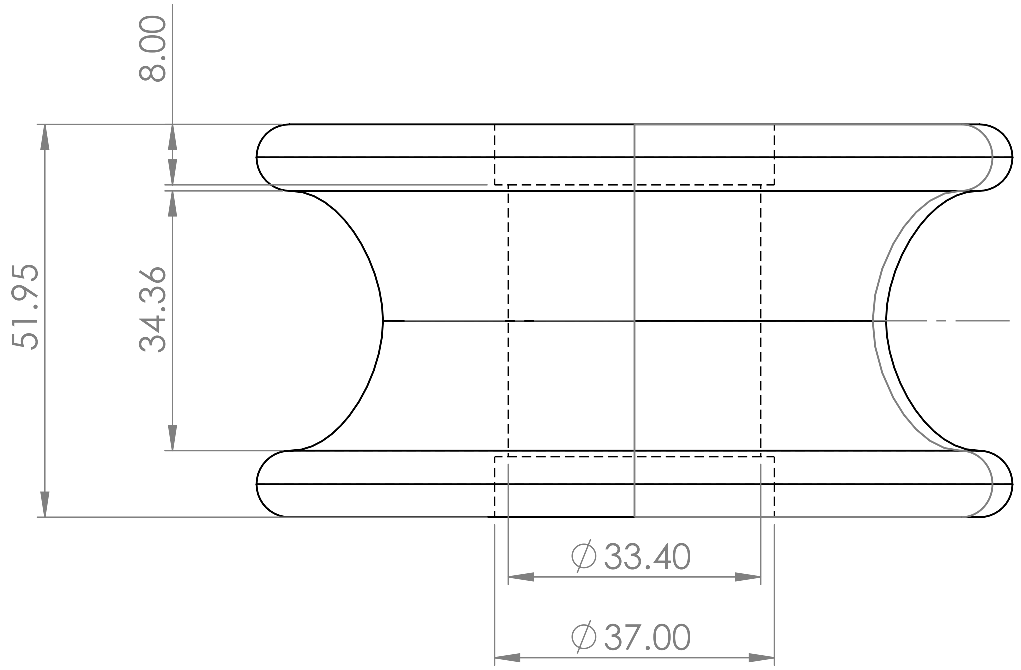
COURSE: System Design
SECTION: 04

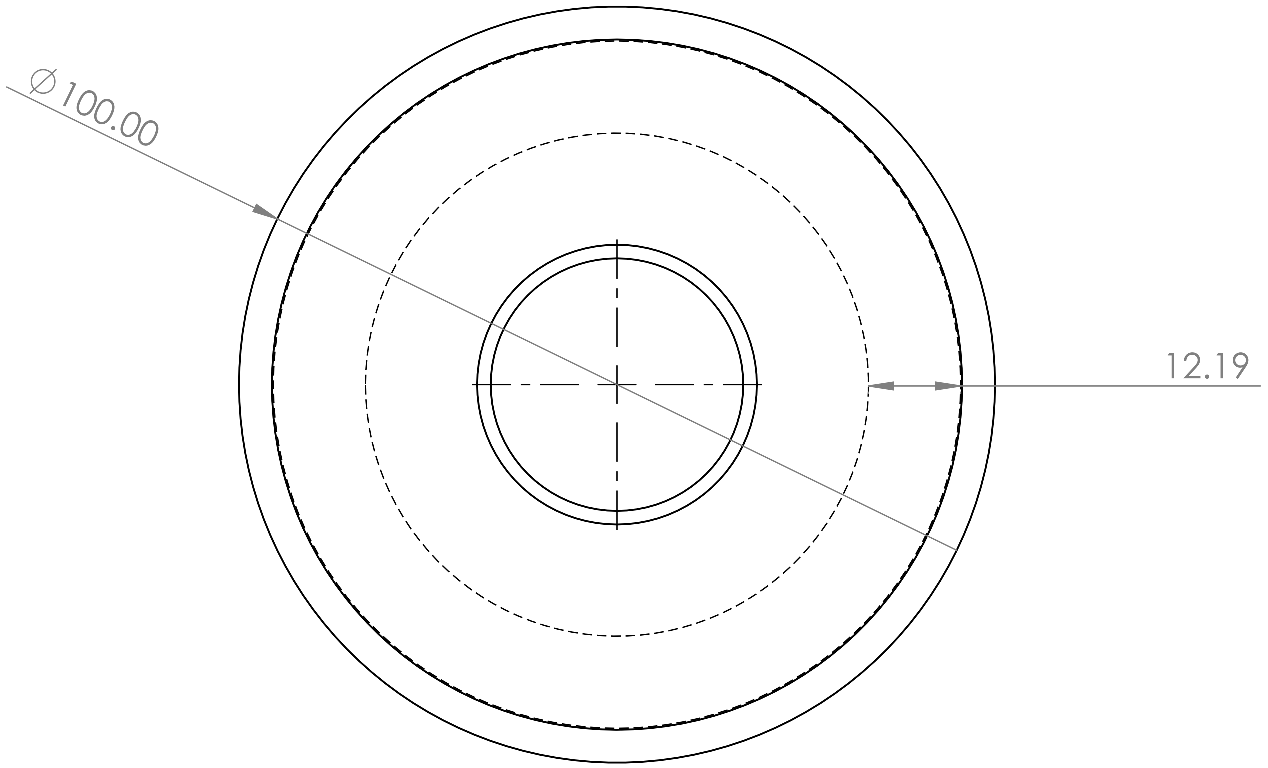
DATE: 07 Feb 25
SCALE: 1:1

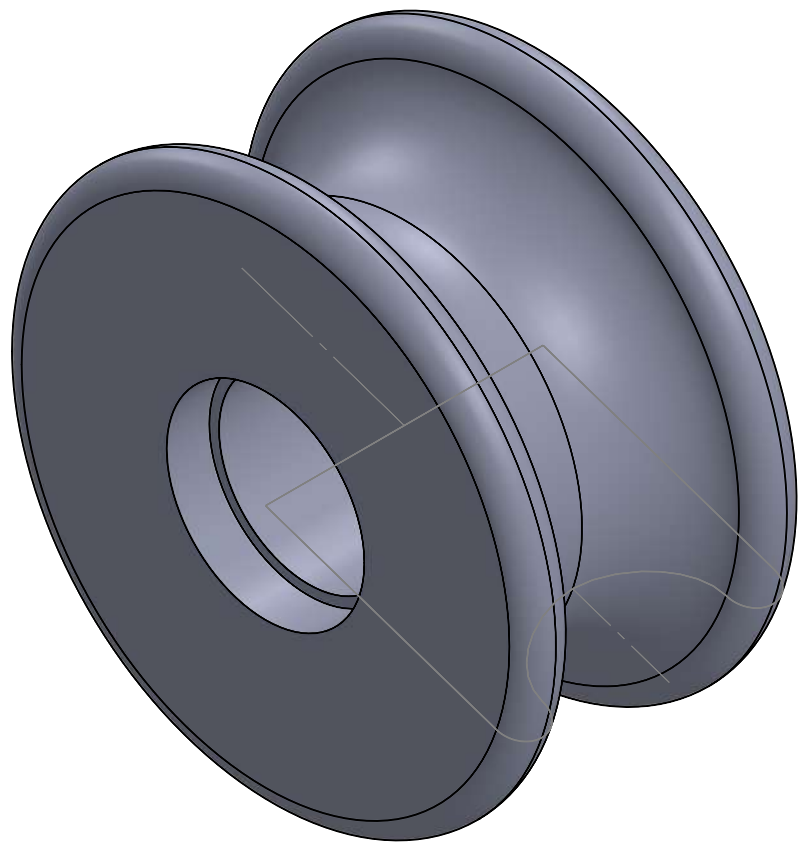


UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING

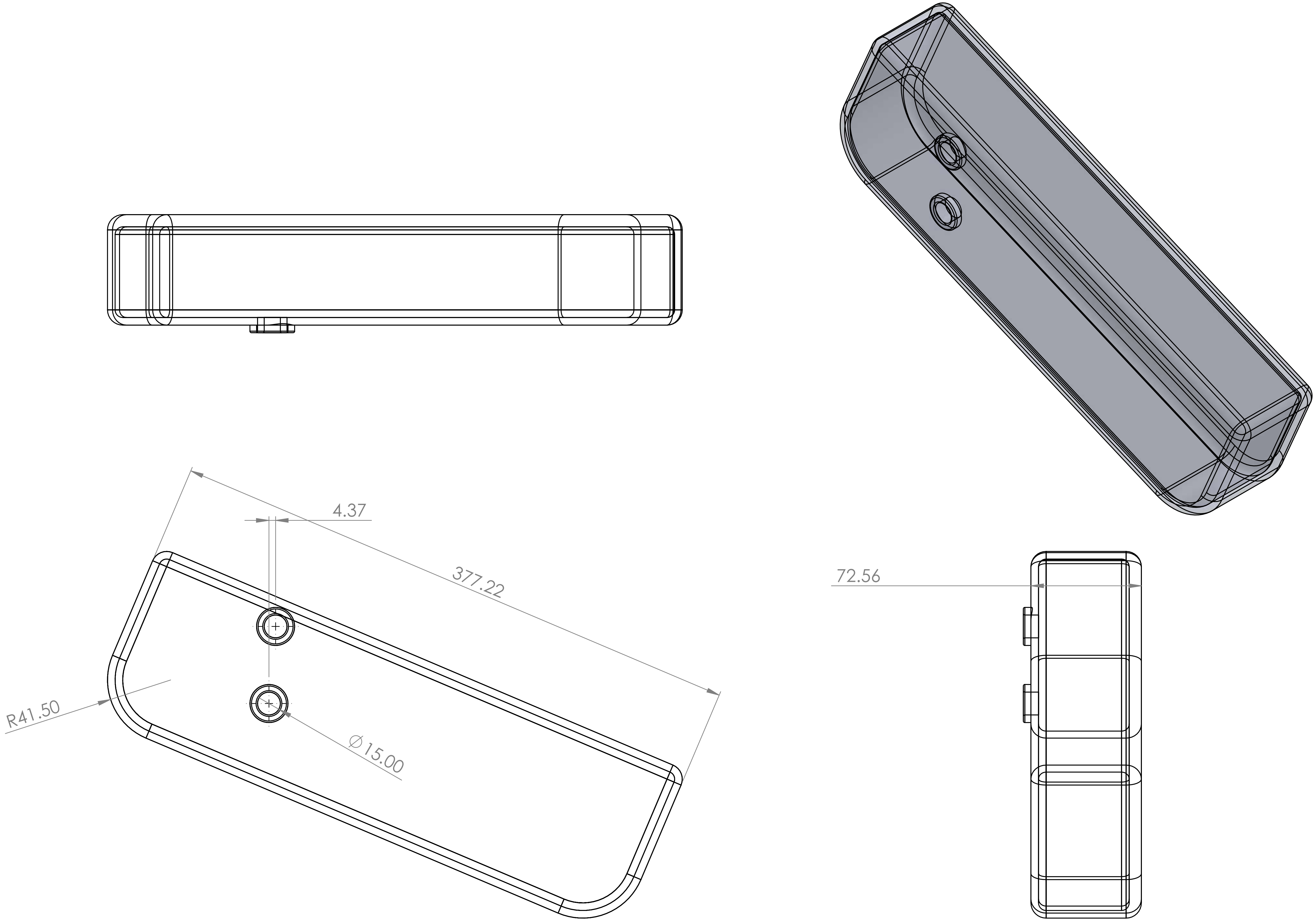
TITLE: Roller Gear	COURSE: System Design	SECTION: 04	DATE: 07 Feb 25
			SCALE: 1:1







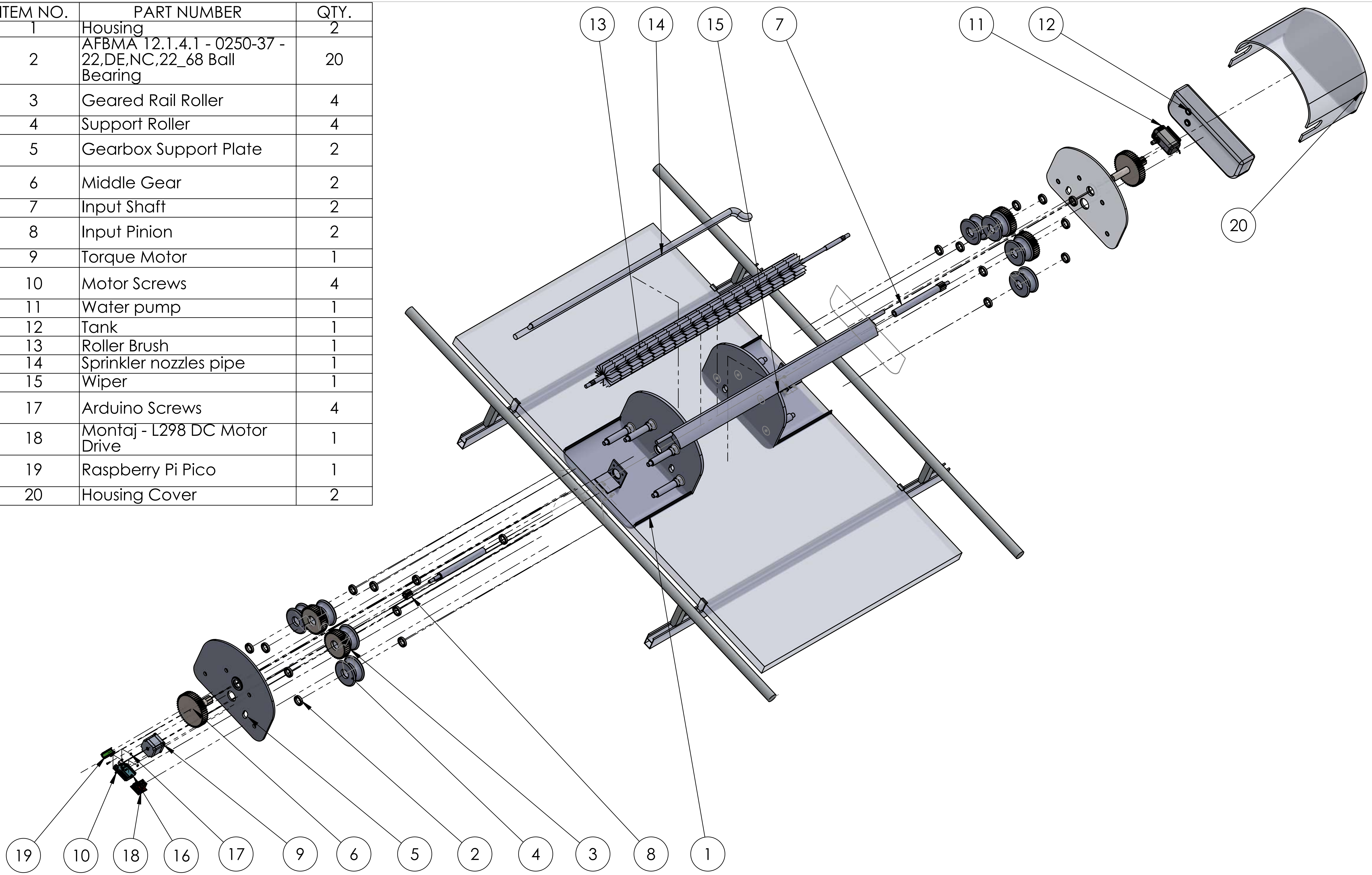
UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: Support Roller	COURSE: System Design SECTION: 04	DATE: 07 Feb 25 SCALE: 1:1



UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING

TITLE:	Water Tank	COURSE:	System Design	DATE:	07 Feb 25
		SECTION:	04	SCALE:	1:2.5

ITEM NO.	PART NUMBER	QTY.
1	Housing	2
2	AFBMA 12.1.4.1 - 0250-37 - 22,DE,NC,22_68 Ball Bearing	20
3	Geared Rail Roller	4
4	Support Roller	4
5	Gearbox Support Plate	2
6	Middle Gear	2
7	Input Shaft	2
8	Input Pinion	2
9	Torque Motor	1
10	Motor Screws	4
11	Water pump	1
12	Tank	1
13	Roller Brush	1
14	Sprinkler nozzles pipe	1
15	Wiper	1
17	Arduino Screws	4
18	Montaj - L298 DC Motor Drive	1
19	Raspberry Pi Pico	1
20	Housing Cover	2



UNIVERSITI TEKNOLOGI MALAYSIA

SCHOOL OF MECHANICAL ENGINEERING

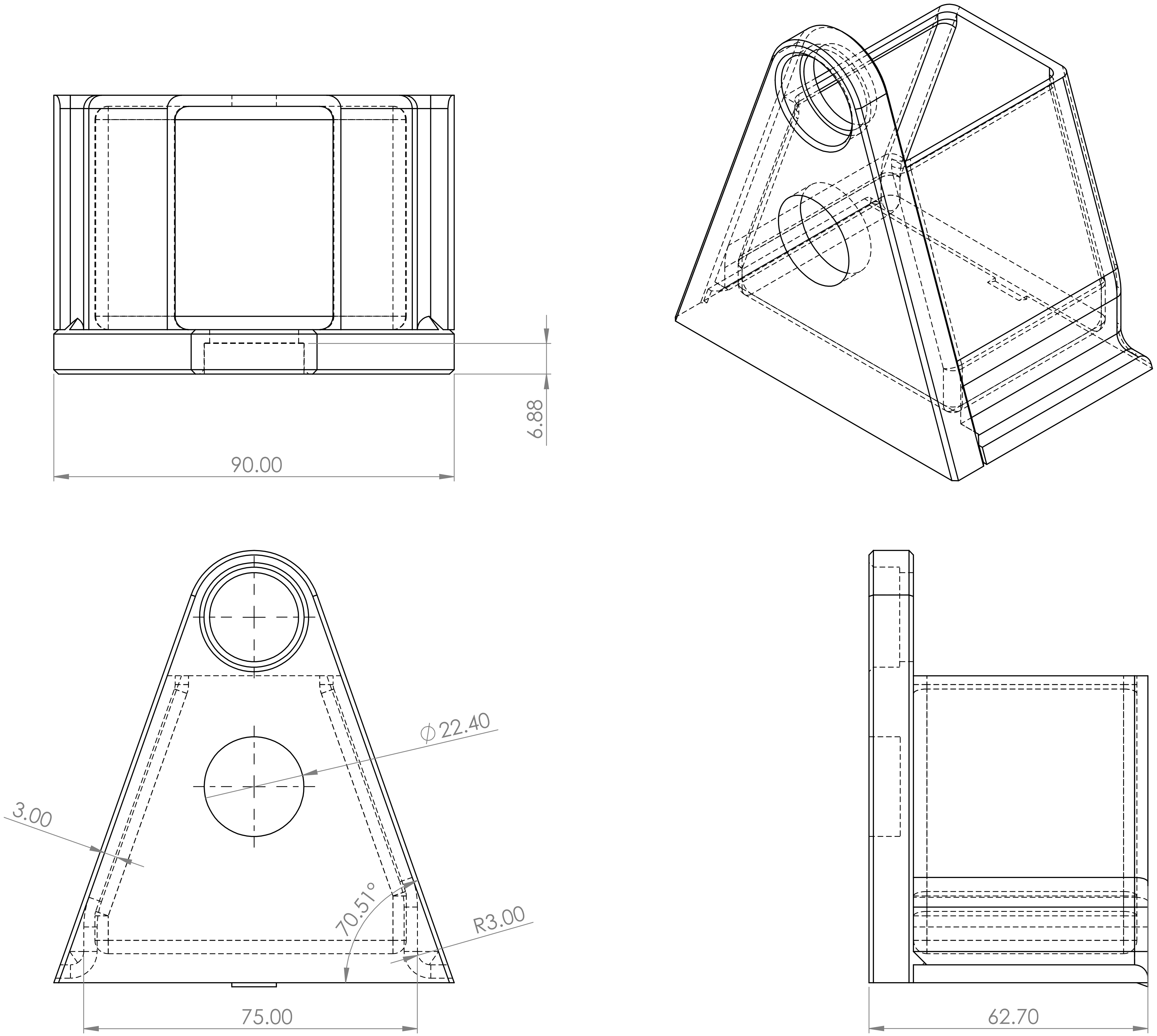
TITLE: HELIOCENTRIC Rooftop Solar Panel Cleaning Device Exploded View Assembly

COURSE: System Design

SECTION: 04

DATE: 07 Feb 25

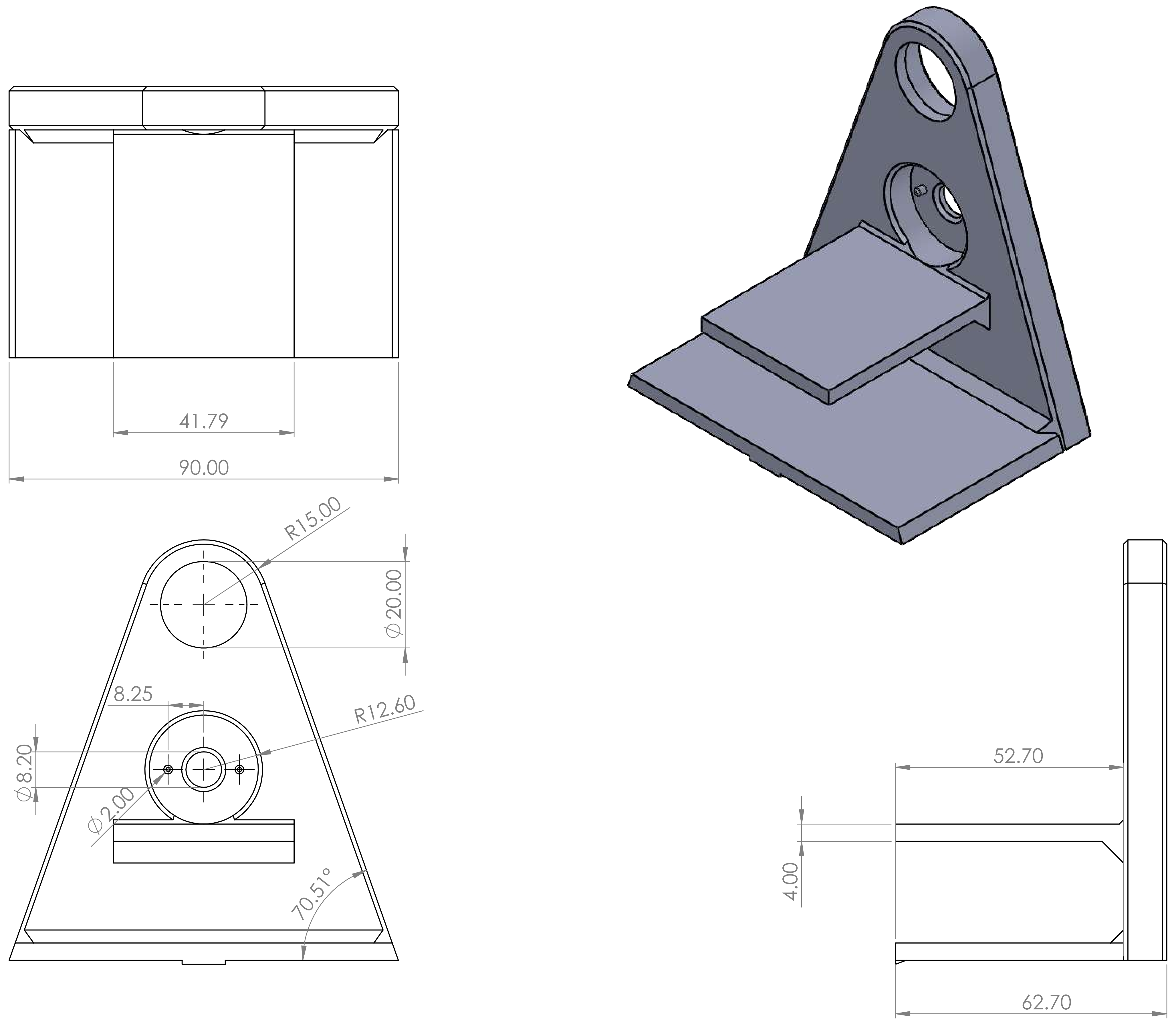
SCALE: 1:12.5



UNIVERSITI TEKNOLOGI MALAYSIA

SCHOOL OF MECHANICAL ENGINEERING

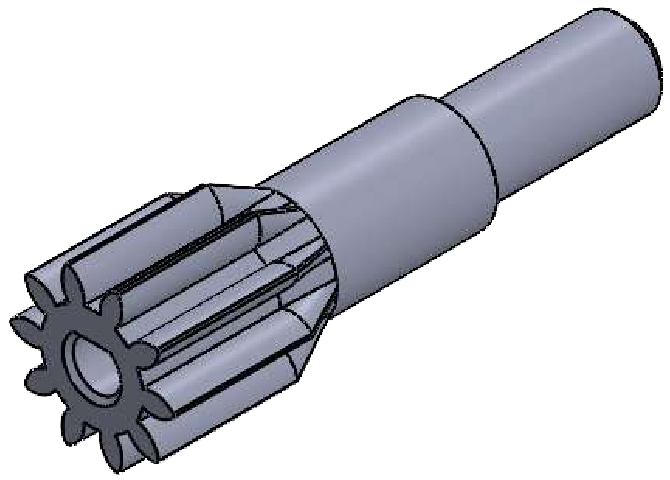
TITLE:	MIDDLE PIECE - PUMPSIDE		
COURSE:	SYSTEM DESIGN	DATE:	09/02/2025
SECTION:	04	SCALE:	1:1

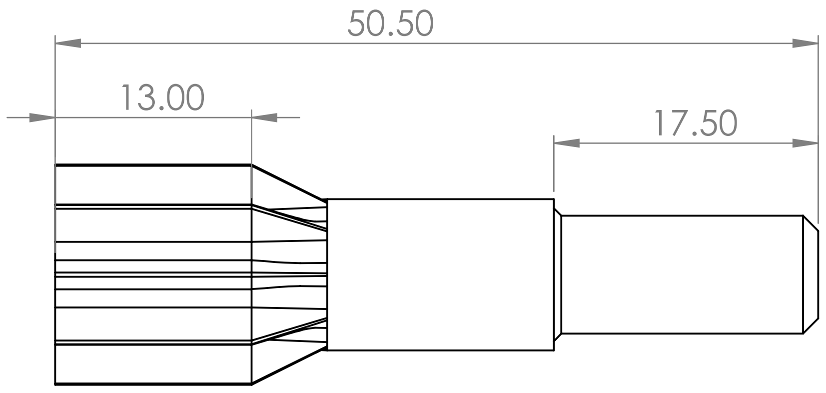


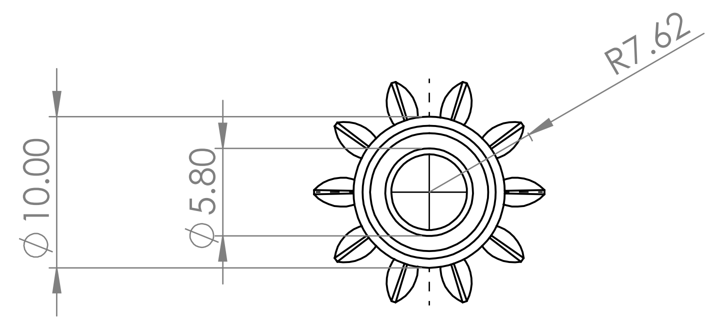
UNIVERSITI TEKNOLOGI MALAYSIA

SCHOOL OF MECHANICAL ENGINEERING

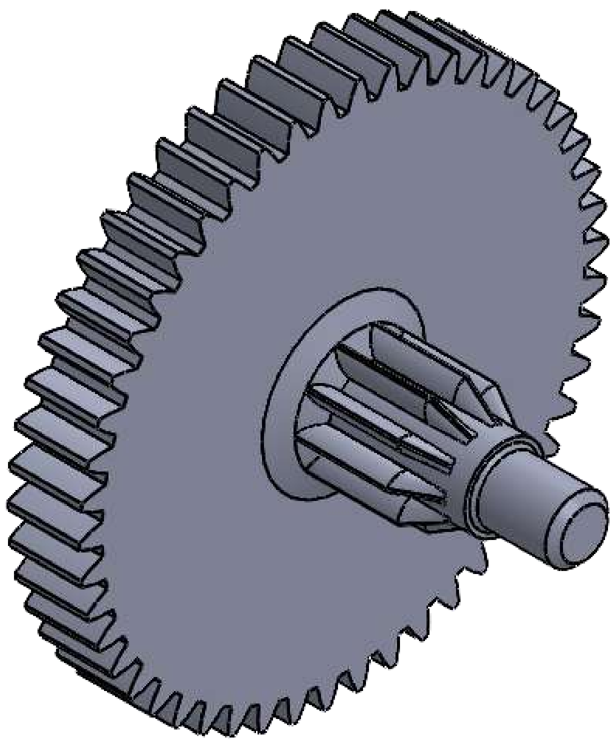
TITLE:	MIDDLE PIECE - MOTOR SIDE	DATE:	09/02/2025
COURSE:	SYSTEM DESIGN	SCALE:	1:1
SECTION:	04		

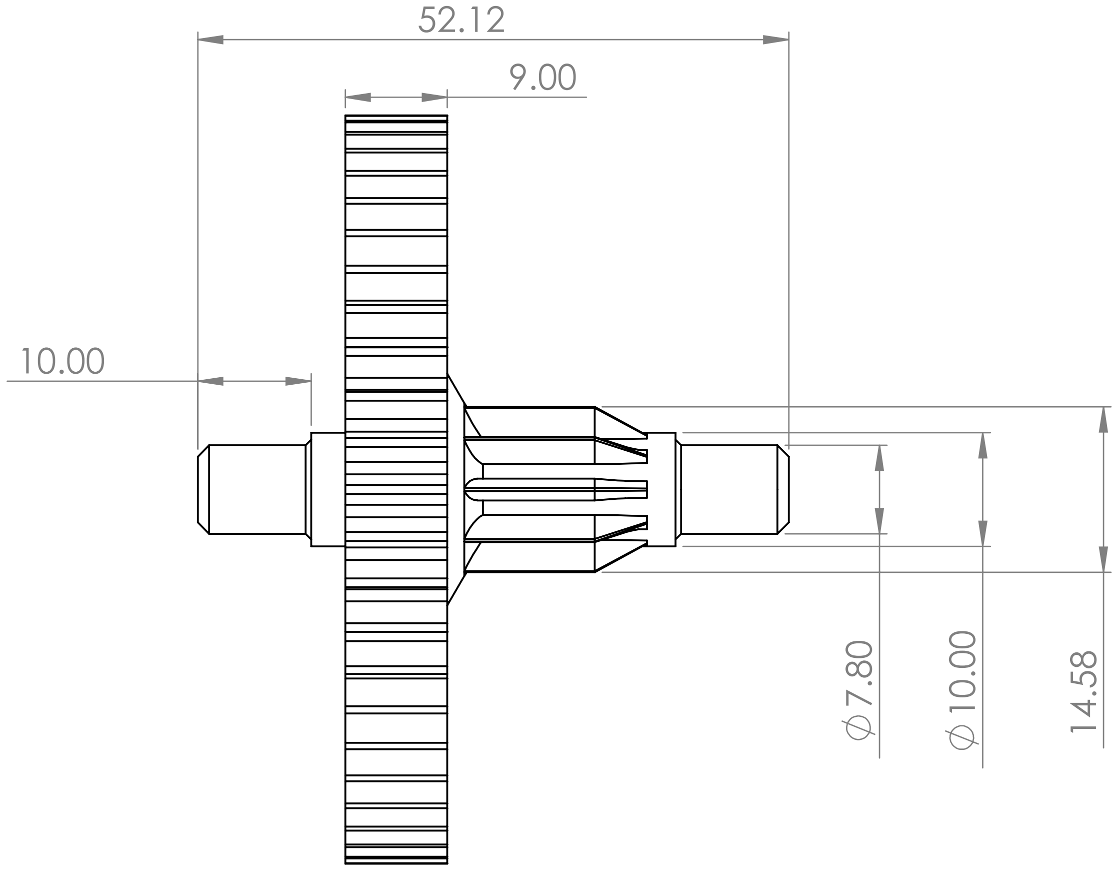


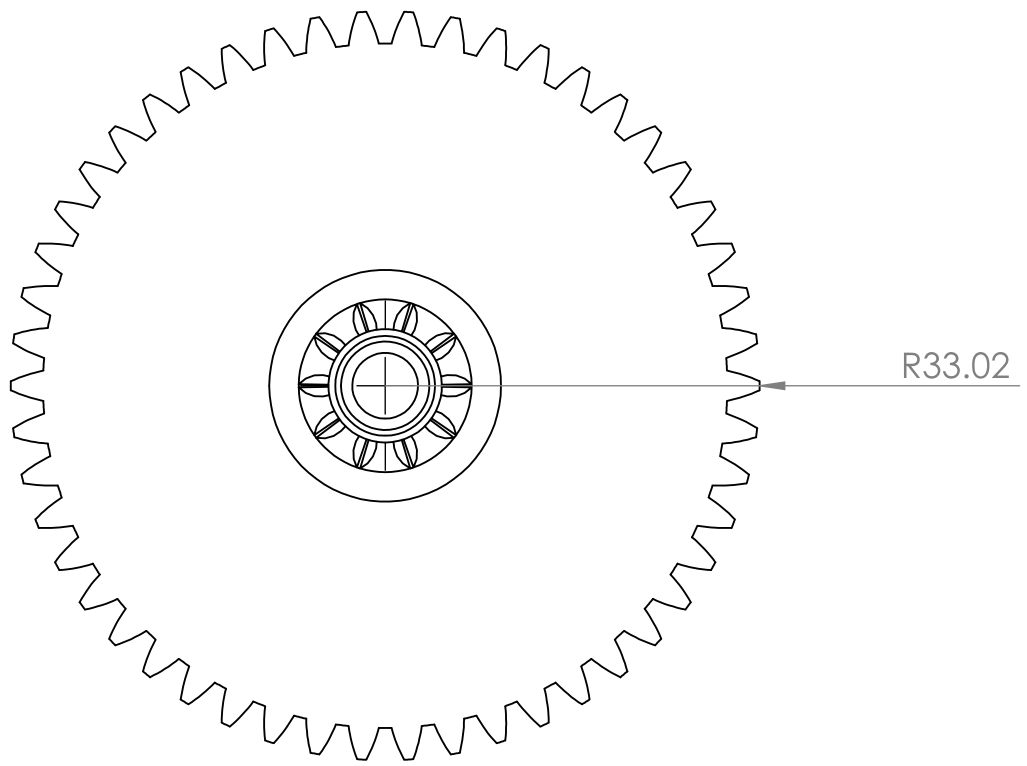




UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: INPUT SPUR GEAR	COURSE: SYSTEM DESIGN SECTION: 04	DATE: 09/02/2025 SCALE: 2:1







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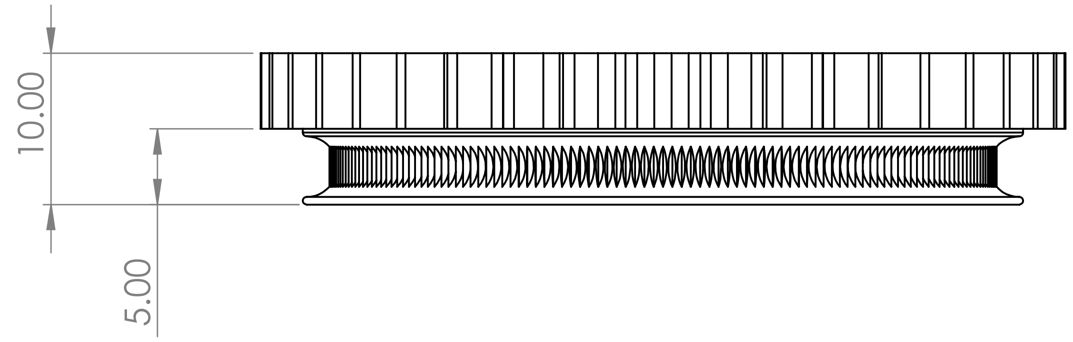
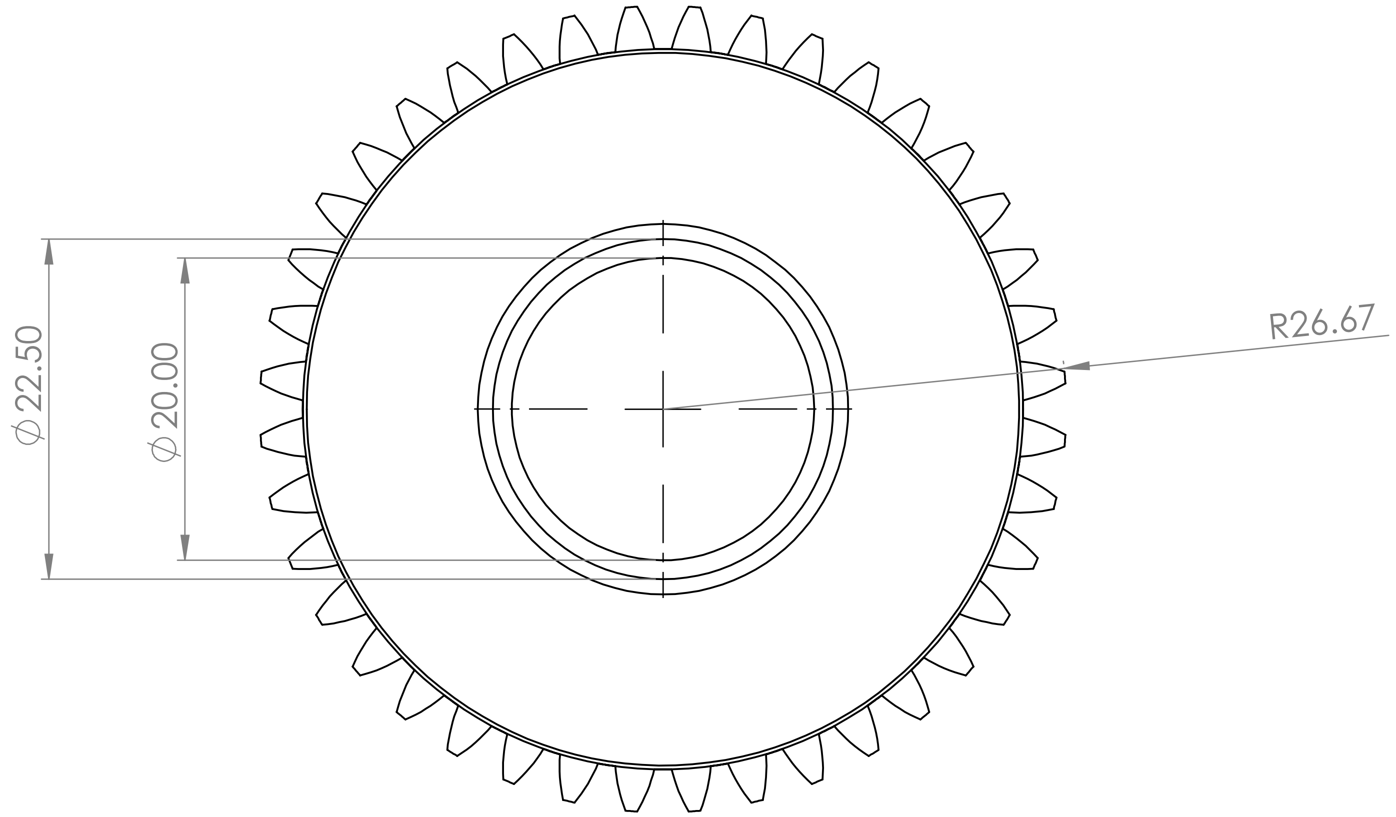
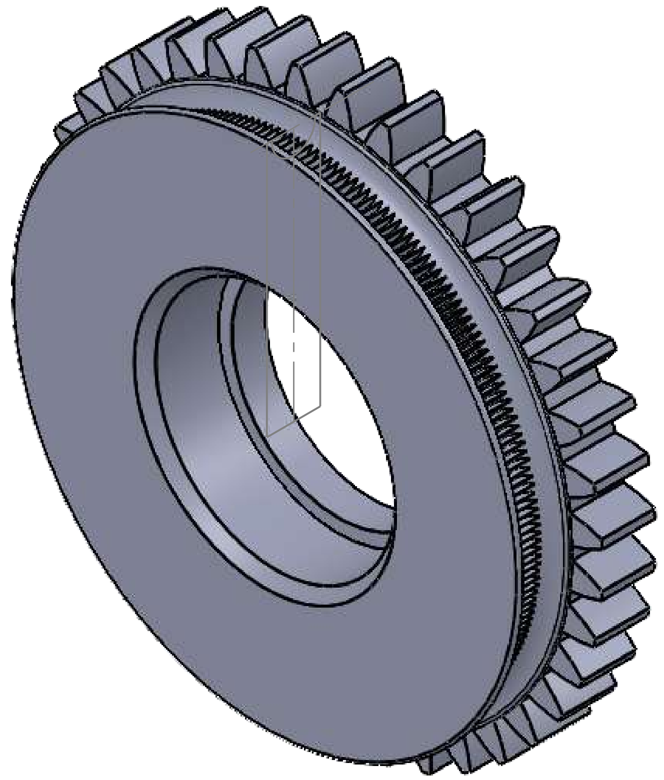
SCHOOL OF MECHANICAL ENGINEERING

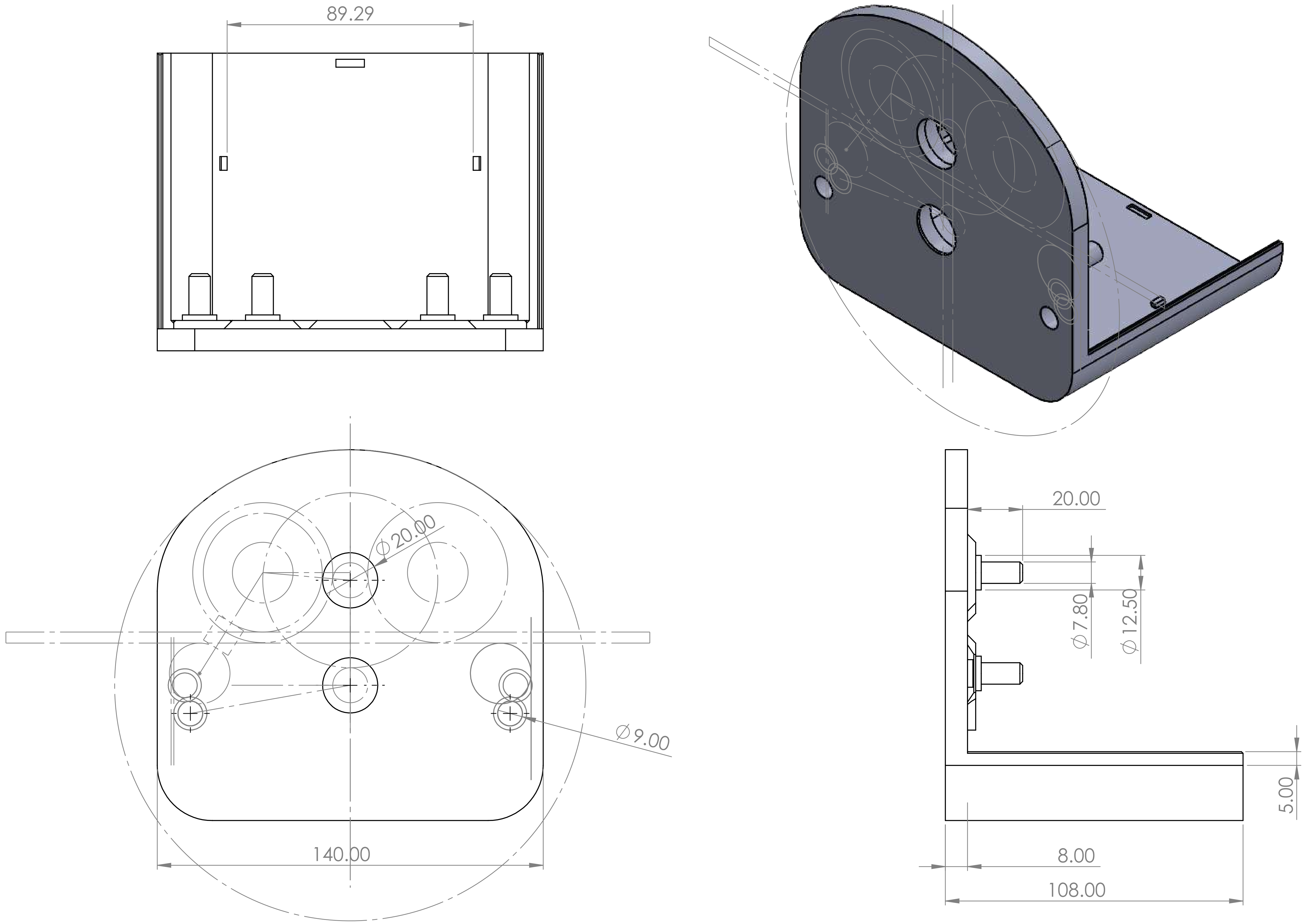
TITLE:	SPUR IDLER MIDDLE GEAR	COURSE:	SYSTEM DESIGN
		SECTION:	04
DATE:	09/02/2025	SCALE:	1.5:1







UNIVERSITI TEKNOLOGI MALAYSIA SCHOOL OF MECHANICAL ENGINEERING	TITLE: ROLLER GEAR	COURSE: SYSTEM DESIGN SECTION: 04	DATE: 09/02/2025 SCALE: 2:1



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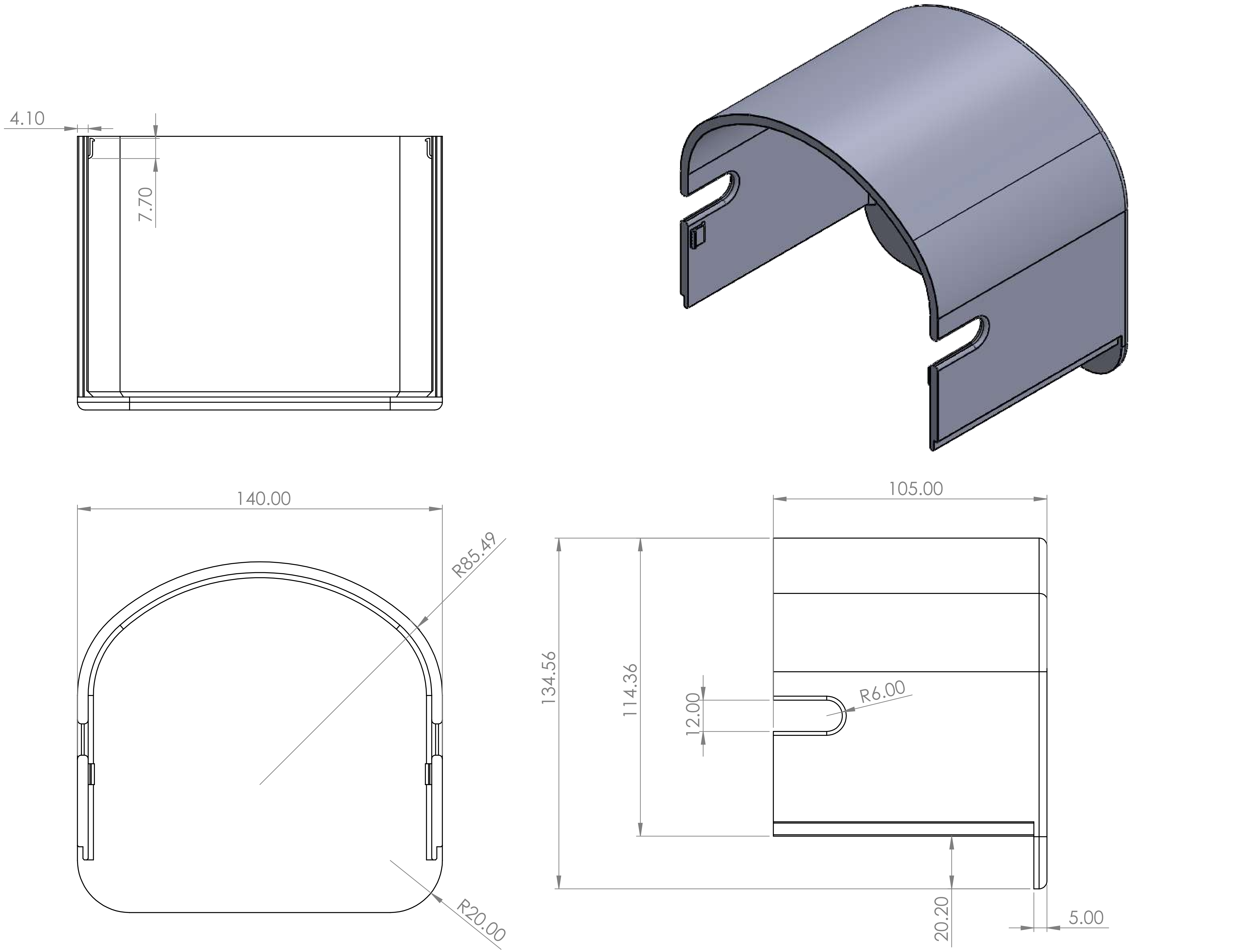
SCHOOL OF MECHANICAL ENGINEERING

TITLE:	HOUSING BASE
COURSE:	SYSTEM DESIGN
SECTION:	04
DATE:	09/02/2025
SCALE:	1:1.5



UNIVERSITI TEKNOLOGI MALAYSIA
SCHOOL OF MECHANICAL ENGINEERING

TITLE:	HOUSING COVER		
COURSE:	SYSTEM DESIGN	DATE:	09/02/2025
SECTION:	04	SCALE:	1:1.5