Abstract

The energy or efficiency produced by solar photovoltaic modules is related with the Sun's available irradiance and spectral content, as well as other factors like environmental, climatic, component performance and inherent system.

Our project concerns the design and development of a solar panel cleaning system. The main goal of this is to enhance Solar PV energy production by designing and manufacturing an automated cleaning system (SPAC) that will be autonomous and remotely monitored.

If the task is done manually, it will be very costly and time consuming. In order to ensure the quality of cleaning, water sprinklers and special wiping material will be used in the designed structure of the mechanism.

The proposed SPAC system will be tested on a part of our PV system over the mechanical engineering building in Zagazig university. The PV system's performance will be evaluated and compared to the baseline performance to measure the improvement.

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Chapter (1) Introduction

1.1 Introduction

Solar Panels are a renewable source of electricity that is widely used worldwide. On the national level, Egypt plans to extend its renewable energy share by 61 % by 2040, with solar PV representing the lion's share of this renewable generation. Here at Zagazig University's main campus, we are not far from this breakthrough in renewable energy generation. A 105 kWp Solar PV system is installed over 6 of the faculty of engineering's buildings. The system is designed, operated, and monitored by the faculty of engineering staff members for more than a year. One of the major problems of Solar systems is the loss of efficiency due to dust deposition, especially in desert dusty regions. A typical system may lose 40% of its energy production if it is not cleaned for a month. Our 105 kWp system suffers a deep energy loss due to the infrequent cleaning process which is a loss of investment. The cleaning process (either wet or dry) represents a good remedy of the problem. This represents a good motivation to find a sustainable and efficient solution for this cleaning problem. This ensures the sustainability of the PV system and improves its economic return.

Figure 1 105 kWp PV system installed at the Faculty of Engineering, ZU.

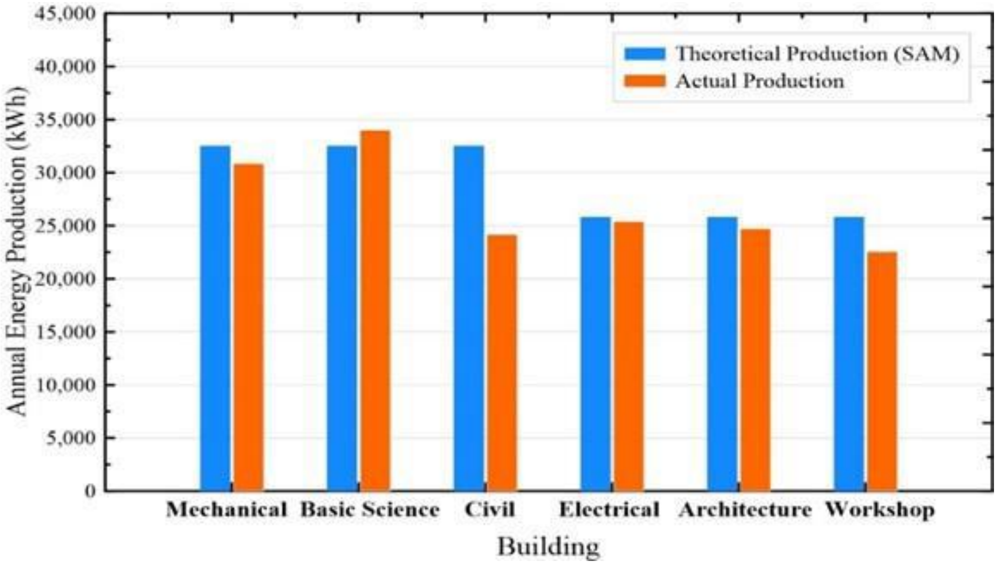

Figure 2 The 105 kWp PV system Performance.

1.2 Key Phases of the project

In our project, we aim to enhance Solar PV energy production by designing and manufacturing an automated cleaning system (SPAC) that will be autonomous and remotely monitored.

Our project includes four key phases: **First,** A full market survey will be performed to figure out the latest technology of Solar Panel Automated Cleaning (SPAC) Systems. A full review of the published scientific literature will be done as well. **Second,** two basic designs will be proposed, one uses wet cleaning with water as the cleaning fluid and the other is a dry-cleaning system to be used at arid and water-scarce regions. The mechanical subsystem will be designed and manufactured locally to reduce costs. All the control components and electric circuitry will be optimised to reduce energy consumption and improve reliability. **Third,** the electronic and electrical components, as well as the controllers and motor drivers are going to be selected. Microcontrollers like the Arduino, ESP32, and Raspberry-Pi are going to be considered as the main brain for the control system. A mobile app is going to be developed to connect to the system wirelessly using Wi-Fi/Bluetooth. Using the app, the user should be able to control the cleaning process remotely and create/monitor cleaning schedules. An automatic cleaning mode could be also triggered through the app. This mode should allow the system to use image processing techniques or specific sensors to check the status of the Solar Panels and perform the cleaning if needed. **Lastly,** the proposed SPAC system will be tested on a part of our PV system over the mechanical engineering building.

SPAC

The PV system's performance will be evaluated and compared to the baseline performance to measure the improvement. The SPAC system will be evaluated in terms of accuracy, automation, energy consumption, water consumption (in wet cleaning systems), the possibility of used water recycling, cost, and reliability at different operating and ambient outdoor conditions.

1.3 The most important results

- Maximizing Energy Production from the PV system.

- Designing and local manufacturing of a cleaning system reduces the manufacturing cost

and ensures the sustainability of the PV project. It also builds the know-how of the technology locally.

- The proposed SPAC will be durable, reliable, energy-efficient, and cost-effective.

Chapter (2) Market Survey

2.1 Methods of solar panels cleaning

Keeping solar panels sparkling clean is key to maximizing their efficiency and reaping the full benefits of your investment. But with a variety of cleaning methods available, in this part, we will discuss these methods.

2.1.1 Mechanical Method

- The mechanical methods remove the dusts by brushing, blowing, Vibrating and ultrasonic driving.
- In the brushing case, Because of the small size and the strong adhesively of the dusts, the cleaning method is inefficient. also, the cleaning machine is powerful. also, the surfaces of the solar cell maybe were damaged by the brush when wiping.
- The blowing method cleaning the solar cell with wind power is an effective cleaning one except for the low efficiency, high energy-consumption.

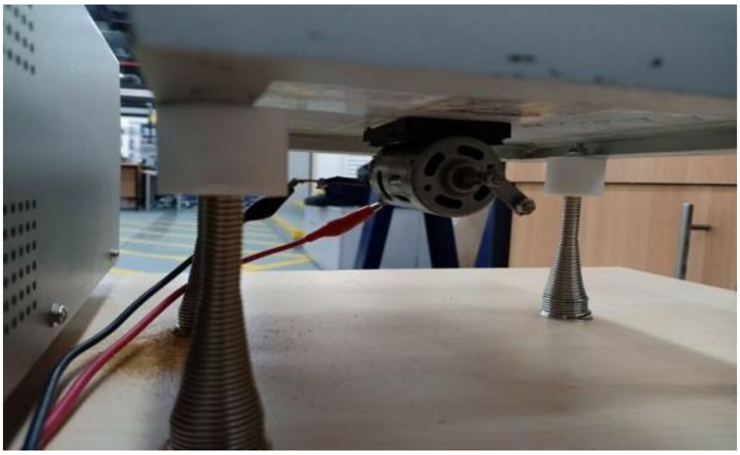

Figure 3 vibrating cleaning.

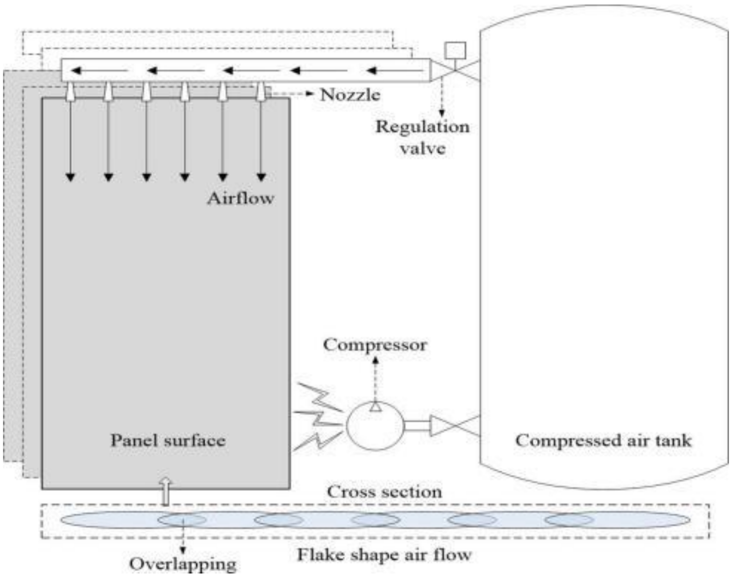

Figure 4 blowing method.

2.1.2 Electrostatic removal of dust

If there is a high potential on the surface of the solar panels, the charged and uncharged dusts will be attracted to the panels because of the electrostatic forces. Then, the dust particles will be charged by the solar panels finally, so they have the same electric charge and the electrostatic forces between them are repulsion. At last, the dust particles will float away the solar panels. This strategy cannot be used in PV systems in rainy places.

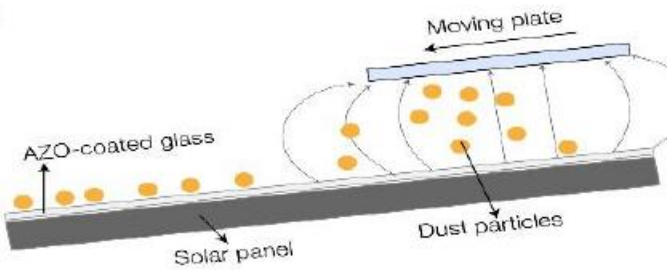

Figure 5 electrostatic removal of dust.

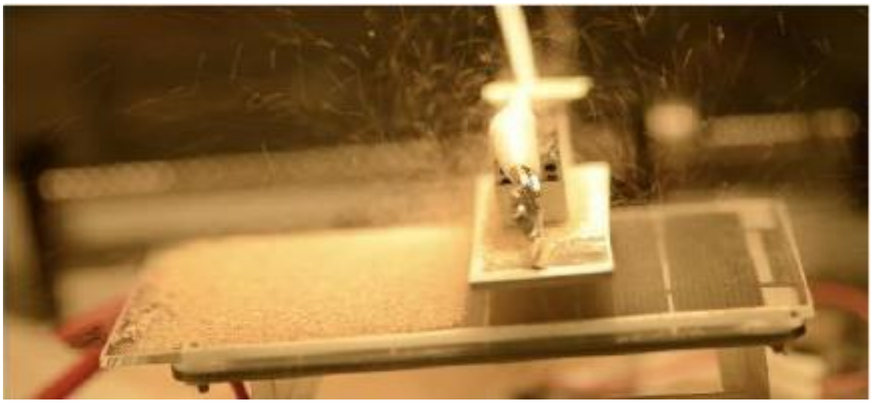

Figure 6 electrostatic removal of dust.

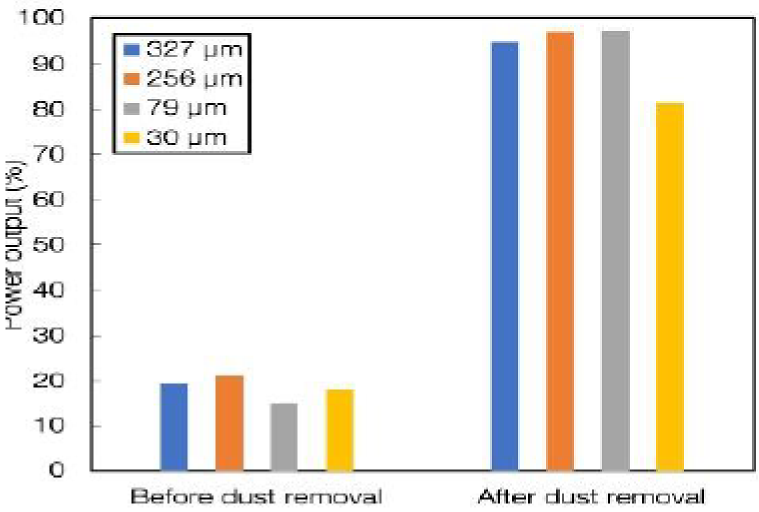

Figure 7 electrostatic removal of dust effectiveness.

2.1.3 Brush Cleaning

The brush cleaning method combines mechanical and electronic components to control the brush's movement as shown in Figure, for cleaning the solar panel either with or without water. The turn-on and turn-off process is automated by sensing the current dust accumulation on the solar panels and comparing it with the set reference by the program. The electronic component supplies a signal to the motor for the cleaning system movement. The system must be robust with many types of complex procedures to be performed with greater precision, flexibility, and control than with conventional techniques. Furthermore, the developed system improves the efficiency and output power of the solar panels as a result of improved performance.

Figure 8 Brush cleaning (Nomad system).

Figure 9 brush cleaning (Ecopia system).

2.1.4 Coating Method

The coating method is also a technique for cleaning solar panels using anti-soiling coating. This method can be used with either a solid, liquid, or gas-based substrate. This method relies on the self-repellent action of the coating material to prevent dust particles from adhering to solar modules.

A startup solar coating company, SunDensity has developed a sputtered nano-optical coating for the glass surface of solar panels that boosts the energy yield by 20 percent, achieved by capturing more blue light than standard cells.

Figure 10 Coating process.

2.1.5 Heliotex Cleaning

Heliotex cleaning involves spraying water onto the solar surfaces. It is possible to program the cleaning system based on the environment whenever necessary. Further maintenance is not required, other than a periodic replacement of the water filter if it is blocked by sand and the top-ups of the cleanser. Pumps are connected via piping to a water reservoir, fixed to nozzles on the solar surface. The system is very effective and recommended for locations with no water deficiency due to the high amount of water consumed for cleaning.

This method of cleaning is not suitable in places where there is no continuous water source, such as solar panel farms located in deserts.

Figure 11 Heliotex cleaning.

2.1.6 Robotic Cleaning

Robotic cleaning of solar panels can be done using dry cleaning or wet cleaning methods. Dry cleaning uses air pressure and dry brushes to release dirt from the surface of solar modules. Wet cleaning is more effective than dry cleaning cause using water in cleaning process helps in dust and dirt removing. There are several robots available for solar panel cleaning, including the F1 SolarCleano, hyCLEANER SolarROBOT, GEKKO Solar Hightec Robot, SUN-X Sunbotics, and SCM S1 Model by Solar Cleaning Machinery.

Figure 12 robot cleaner (dry type)

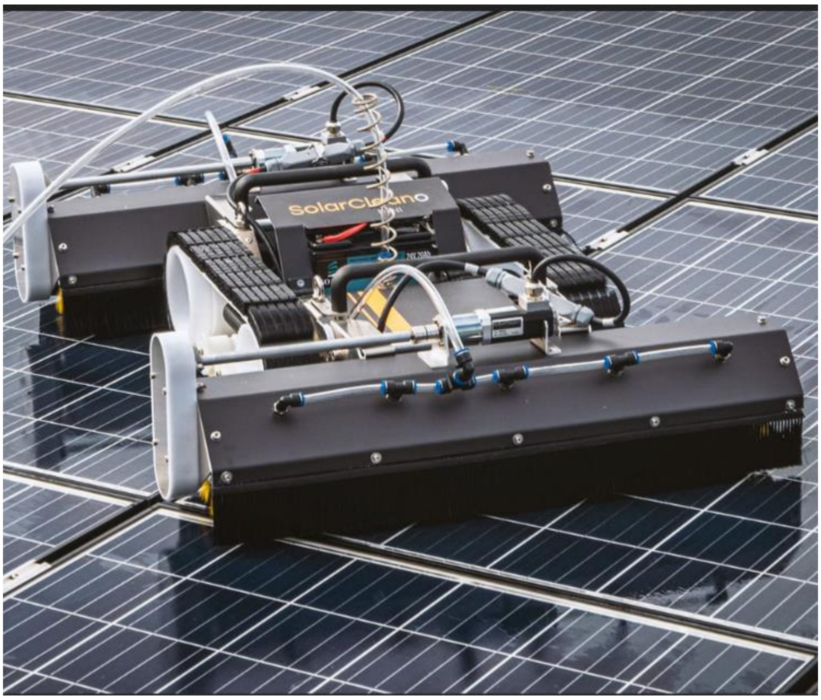

Figure 13 robot cleaner (wet type).

SPAC

2.2 Comparison between cleaning methods

Table 1 comparison between cleaning methods.

Cleaning Technique	Merits	Demerits	Power Output Efficiency Compared to Clean Panels
Natural cleaning	No investment cost	Depends on weather	4%
Manual cleaning	Simple design	Requires expensive materials and labor	90.67%
Robotic cleaning	Effective and sustainable in all climates	Requires complex construction	99.5%
Heliotex cleaning	Effective for non-sticky dirt	Requires a lot of water	12.5%
Electrostatic cleaning	Effective for dry dust, no moving parts	High voltage required, costly design	3.35-11.5%
Hydrophobic and hydrophilic coating	No water or labor required	Coating reduces screen efficiency	6.62%
Vibrating cleaning system	Applicable for dry dirt in dry weather	Requires external power source	95%
Forced-air cleaning system	Applicable for dry dirt in dry weather	Requires external power source	86.4%

2.3 Dry and Wet cleaning

Keeping photovoltaic systems clean is essential for optimal performance. Solar maintenance is considered an important part of panel longevity and should be done regularly to maximize the life of the system. Cleaning can be done through either wet or dry methods, In this part, we will make a comparison between dry and wet cleaning, as well as compare their costs.

Table 2 comparison between wet and dry cleaning.

Feature	Dry Cleaning	Wet Cleaning
Cleaning method	Brushes, electrostatic cloths, specialized dry cleaning pads.	Heliotex cleaning method and wet robotic cleaner.
Cost	Less expensive equipment because there is no need for the pump and piping system.	More expensive equipment, may require additional water and cleaning solution costs, such as piping, nozzles, valves, and pump.
Ease of use	Very simple and quick	Requires more setup and preparation, can be physically demanding
Water usage	Minimal water usage	Requires water, potentially large amounts depending on method.
Effectiveness	Removes loose dirt, dust, bird droppings	More effective at removing stubborn dirt, grime, stains, and bird droppings
Frequency	May require more frequent cleaning	May require less frequent cleaning due to deeper clean
Suitability for:	Regular maintenance, gentle cleaning	Deep cleaning, heavily soiled panels, areas with limited water availability
Environmental impact	Less resource-intensive	Water usage may be a concern in some areas
Safety	Generally safe	Pressure devices can be dangerous if used improperly, potential electrical hazards with wet panels.

2.4 Models on the market

2.4.1 GEKKO solar hightec robot

This robot is Designed to clean PV panels on roof tops and solar farms, which are difficult to access, it's best suited for cleaning companies, offering their service to PV plant owners.

The GEKKO Solar cleans rigorously by rotating brushes, executing a constant pressure on the panels and the use of demineralized water.

It Is typically used together with a mobile work platform: from here, the operator can lift the robot comfortably to the roof and control it by radio using a joystick.

GEKKO Solar is also suited for small solar farms with narrow panels. In this case, a support wagon supplying water, electrical power and pressurized air ensures an independent operation.

Figure 14 GEKKO robot.

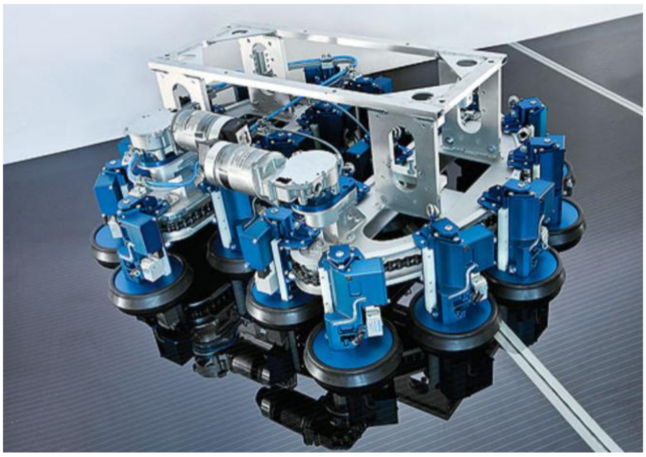

Figure 15 GEKKO robot.

Main specifications:

- High cleaning efficiency: 4 times faster than manually.

SPAC

- Easy handling: operating by joystick and radio control.
- Cleaning efficiency reaches maximum up to 1'040 m2 per hour.
- Average cleaning efficiency reaches up to 670 m2 per hour.
- Easy operation little trolley for water an energy supply with a hose of about 100 m in length.
- Precise cleaning: with even quality.
- Steep rooftops included: up to 45°.

The price: 2,161.67 $ =66,904.00 EGP

2.4.2 SUN-X Sunbotics

This is a cross-product modular system with individual extensions. Different sized robots manage different levels of inclination. The most important parts of the Sunbotics series are the motorized quick coupling System and the intelligent carrier arms. Every Sunbotics product is based on these two features. Most of the other products are always included but Sunbotics product will be expanded in just a few simple steps. Disassemble the equipment conveniently and quickly on the ground and reassemble the individual parts on the roof. Sunbotics carrier arms have a high strength aluminum core, having a lower overall weight.

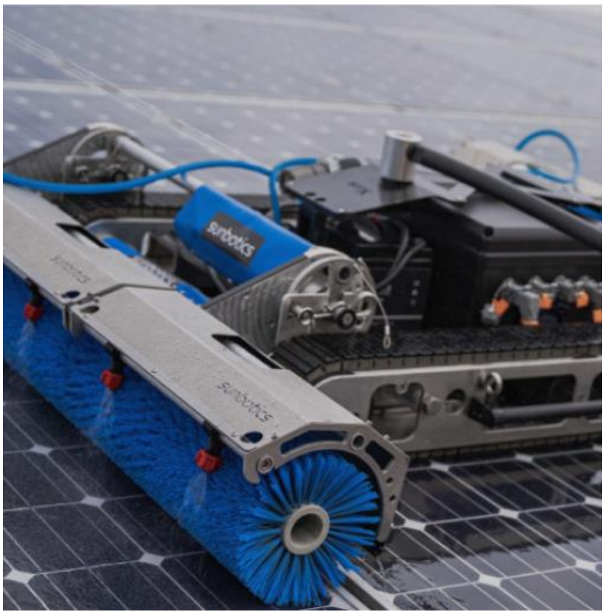

Figure 16 SUN-X Sunbotics robot.

SPAC

Figure 17 structure of SUN-X Sunbotics robot.

Main specifications:

- The suspension system is equipped with a remote control of about 100m range.
- Clean on up to 25° with a 1,45 m brush size, the larger versions with a 2,10m or 3,20m brush size can drive on up to 20°.
- Power & battery operated - the sunbotics e-Boxes are available in different versions, all operated either via power connection or rechargeable battery.
- Overcoming obstacles - Overcomes module gaps of up to approx. 60 cm. Height-adjustable brushes that allow to easily overcome slight height differences of up to approx. 15 cm.
- Anti-splash - The robust splash guard is made of truck tarpaulins.
- Integrated water tanks.
- The shifted brushes ensure that best possible cleaning results.
- The specially designed rubber profiles of the chains easily provide extra grip for vertical driving on inclinations of up to 25°.

The price: 3,500.00 $ =108,144.40EGP

2.4.3 SCM S1 Model

The S1 Model by SCM is an automatic programmable robot with a double brush system. Individual or interconnected by groups.

Figure 18 SCM S1 Model (individual).

Figure 19 SCM S1 Model (interconnected).

The price: 4,700.00 $ = 145,222.48 EGP

2.4.4 Hy cleaner super robot

The Hy CLEANER specializes in cleaning ground-mounted PV systems and roof-mounted installations. In just a few steps, the machine is mounted and ready for use without the need of any tools. The integrated automated driving function with lane keeping system and speed control, allows the machine to drive independently over the panels. Thanks to the standard edge detection system with fall protection sensors, the robot stops automatically when it reaches the edge of the solar panel.

SPAC

Figure 20 Hy cleaner super robot.

Main specifications:

- Easy operation via radio-remote-control with a range of 100m.
- Adjustable driving speed.
- Self-supporting brush that also ensures an easy cleaning of the edges.
- Cleans even on transverse slopes.
- The surface load is considerably below the allowed wind and snow loads.
- Easy to handle due to its modular design and lightweight components.
- Several fixing and fastening points allow a flat positioning of the solar panel cleaning robot on the solar surface.
- All types of water treatment systems and osmosis plants can be used.
- Easy change of the driving pads via Velcro fastener.
- Operating pressure 2-8 bar.
- Minimized water consumption.
- The price: 28,000 euros = 941,284.40 EGP

Chapter (3) Model Description

3.1 Our model

3.1.1 Introduction

Our model is a solar panel cleaning robot that runs on two belts. It consists of two brushes on the front and back of the robot and four motors. Each belt operates using a motor. The other two motors are for the brushes.

The robot uses a water sprinkler system and oscillating brush mechanism. This is an autonomous robot which will clean the solar panel surfaces without any manual support. It is also Can comprise of both water-based or waterless techniques.

3.1.2 Advantages and Disadvantages of this model

Advantages:

- The ability to clean solar panels with both water and dry methods.
- Sufficient sensors to operate independently.
- Distant monitoring of real-time plant conditions.
- Requires no human intervention.
- Cleaning supervision can be done distantly.

Disadvantages:

- Complexity of the system.
- High initial investment.
- Not suitable for all configurations.
- Ineffective against some dirt.
- Weather dependence.
- Operating costs for wet cleaning especially.

3.2 Mechanical Subsystem

SolidWorks Design:

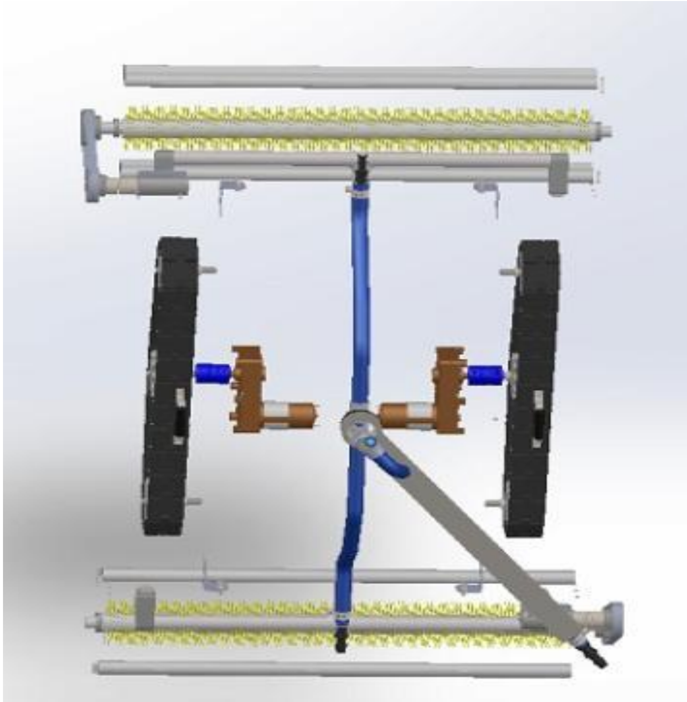

Figure 21 SolidWorks design without the cover.

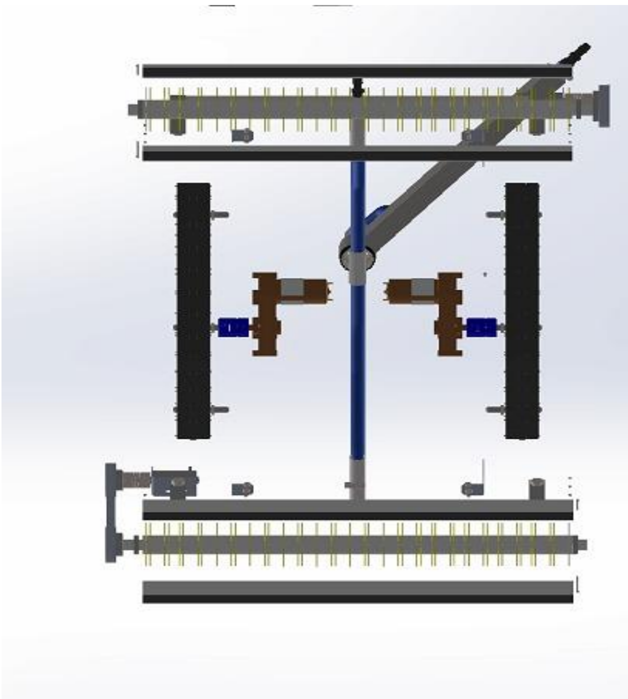

Figure 22 SolidWorks design without cover (bottom view).

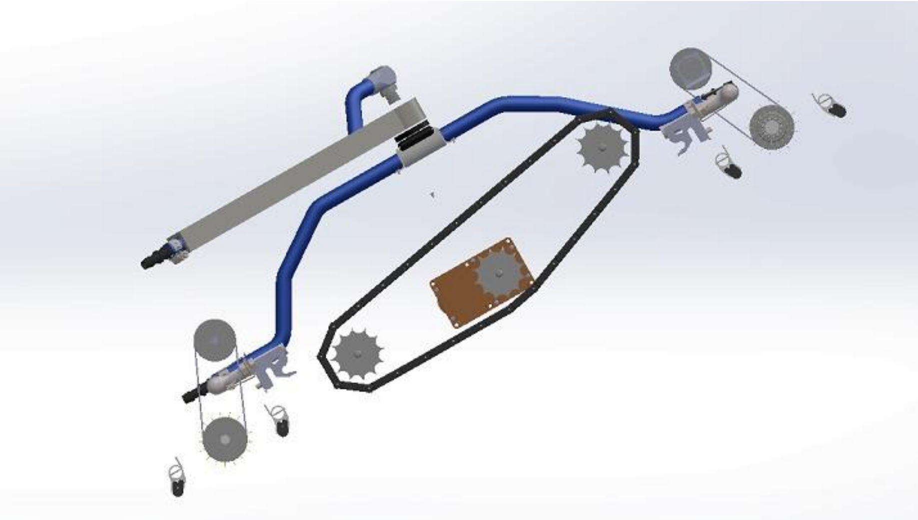

Figure 23 SolidWorks design without cover (side view).

Mechanical subsystem consists of:

1- 4 Motors:

Motors are used to move the belt in all directions. There is a motor on the first belt, and there is a motor on the second belt, and there are also two motors for moving the brushes in the front and back.

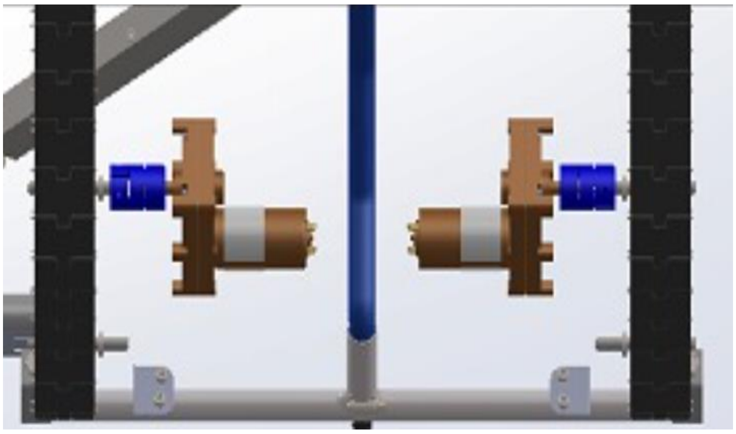

Figure 24 belts motors

2- Brushes:

Brushes play a vital role in keeping solar panels clean and functioning efficiently. By choosing the right type of brush which will not create scratches in the solar panels, and maintaining them properly, we can ensure that the solar panels are generating the maximum amount of energy.

Types of brushes:

i) Rotating brushes:

These are the most common type of brush, typically made of soft bristles like nylon or microfiber. They spin at high speeds (around 100-200 RPM) to effectively dislodge dirt and grime.

Figure 25 Rotating brush.

ii) Spiral brushes:

These brushes have a spiral-shaped design that helps to loosen and lift stubborn dirt particles. They are often used in conjunction with rotating brushes for a more thorough cleaning.

Figure 26 spiral brush.

3- Shafts:

The shafts in the solar panel cleaning robot play a crucial role in its movement and cleaning mechanisms.

4- Belts:

These are typically toothed belts or timing belts that are used to transmit power from the robot's motor to its wheels or tracks. This allows the robot to move across the surface of the solar panels.

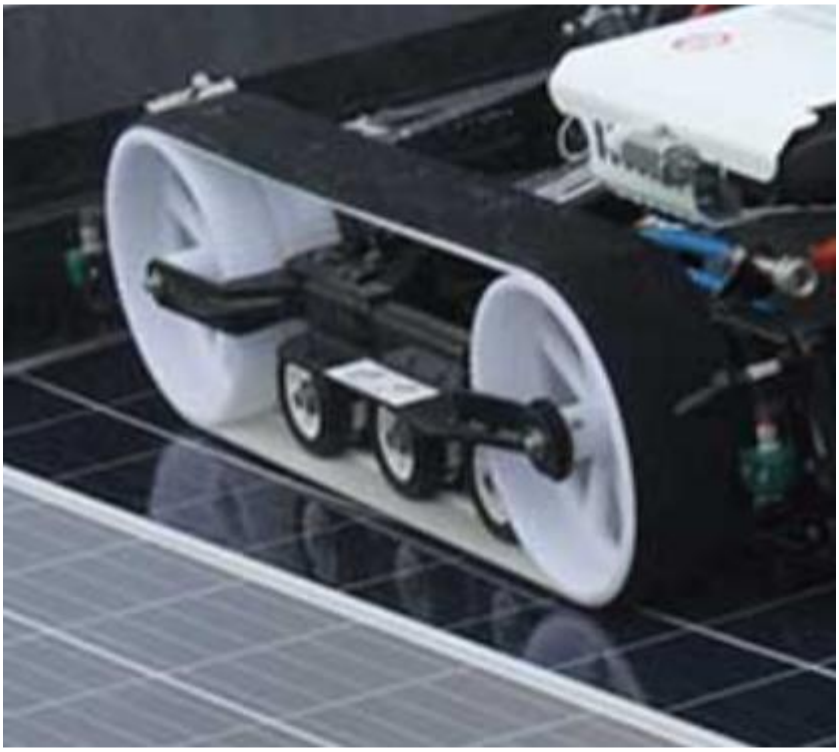

Figure 27 robot belt.

5- Pump:

The pump in a solar panel cleaning robot is a crucial component that plays a vital role in the cleaning process. Its main function is to draw water from the robot's onboard tank and deliver it to the spraying nozzles, ensuring an even distribution of water across the solar panel surface.

There are two main types of pumps used in solar panel cleaning robots:

Submersible pumps: These pumps are placed directly inside the water tank and are completely submerged in water. They are typically more compact and energy-efficient compared to external pumps.

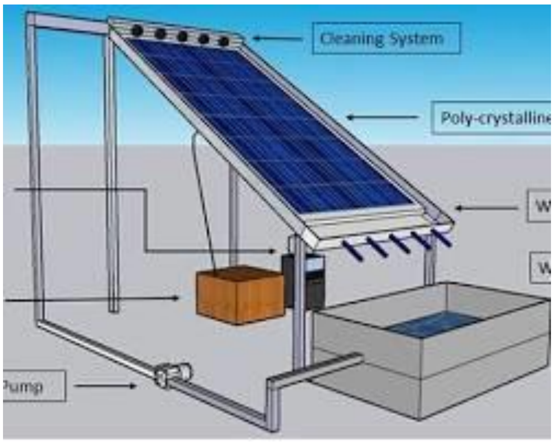

Figure 28 Submersible pump in Heliotex cleaning method.

i) External pumps: These pumps are mounted outside the water tank and are connected to it with hoses. They offer more flexibility in terms of placement and can be easier to service or replace.

Figure 29 External pump in manual cleaning.

3.2.1 Modification

As a result of the difficulty of implementing a robot that moves on a belt, due to the cost, complexity of the design and other factors, we have taken into consideration another design that relies on four wheels of a specific type that are non-slip (Mecanum wheels).

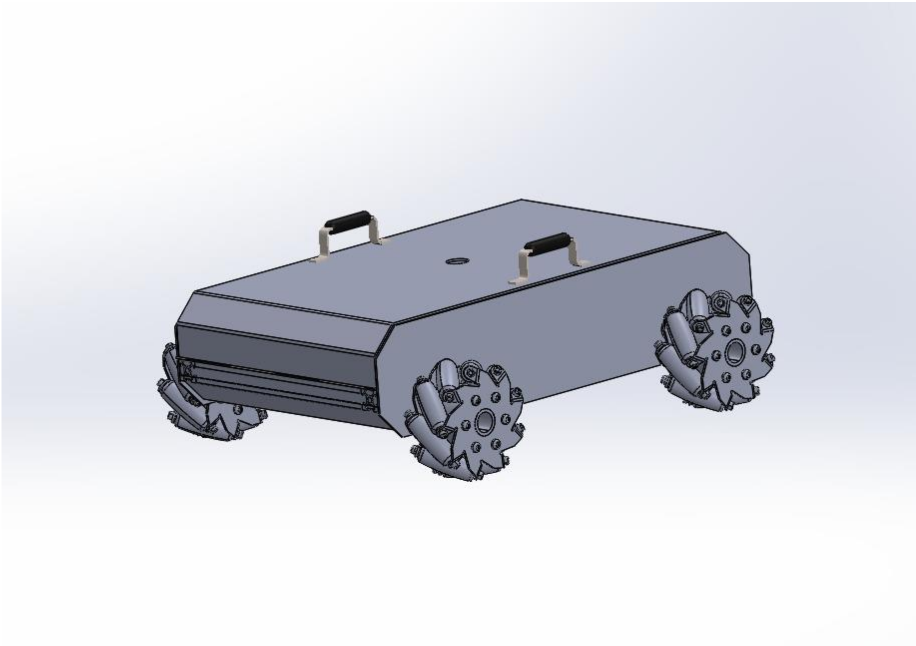

Figure 30 SolidWorks modified design.

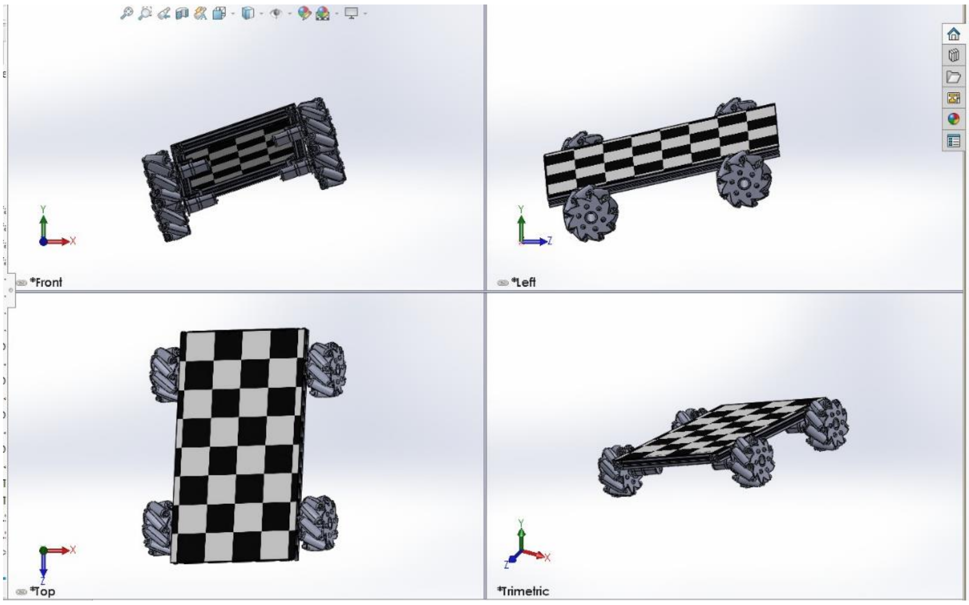

Figure 31 SolidWorks modified design (different angels).

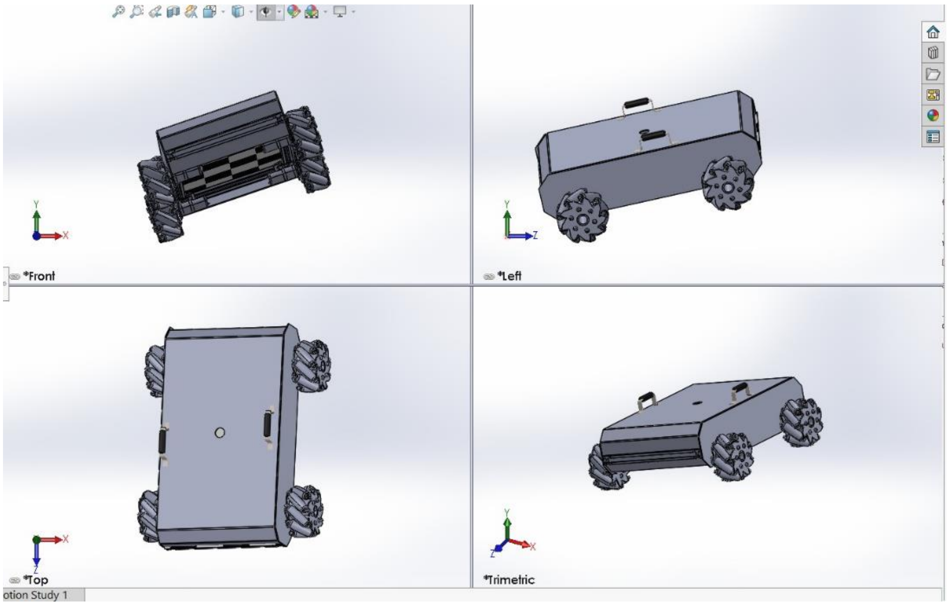

Figure 32 SolidWorks modified design (with cover)

- Mecanum wheels:

The mecanum wheel is a form of tireless wheel, with a series of rubberized external rollers obliquely attached to the whole circumference of its rim. These rollers typically each have an axis of rotation at 45° to the wheel plane and at 45° to the axle line. Each Mecanum wheel is an independent non-steering drive wheel with its own powertrain, and when spinning generates a propelling force perpendicular to the roller axle, which can be vectored into a longitudinal and a transverse component in relation to the vehicle.

Figure 33 Mecanum wheel.

3.3 Control Subsystem

3.3.1 Introduction

STM32 microcontrollers have become an integral part of modern technology, powering a wide range of applications in industries such as automotive, consumer electronics, robotics, and industrial automation.

In this blog post, we will delve into the key features that make STM32 microcontrollers stand out from their competitors. By understanding these features, you will gain a deeper insight into the capabilities and potential of STM32 microcontrollers.

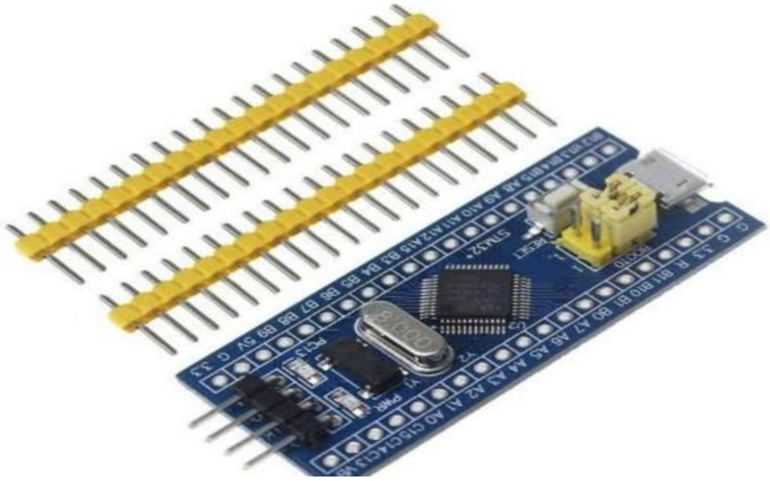

Figure 34 STM32.

3.3.2 Features

Processing speed: STM32 microcontrollers are known for their high processing speed, allowing them to execute instructions quickly and efficiently.

Memory capacity: These microcontrollers come with a generous amount of flash memory for storing program code and data. Additionally, they also have separate RAM for temporary storage.

Power efficiency: STM32 microcontrollers are designed to operate with low power consumption, making them ideal for battery-powered and energy-efficient applications.

Peripheral integration: These microcontrollers have a wide range of built-in peripheral modules, including UART, SPI, I2C, USB, GPIO, and timers. This integration simplifies the design and implementation of complex systems.

3.3.3 Methodology

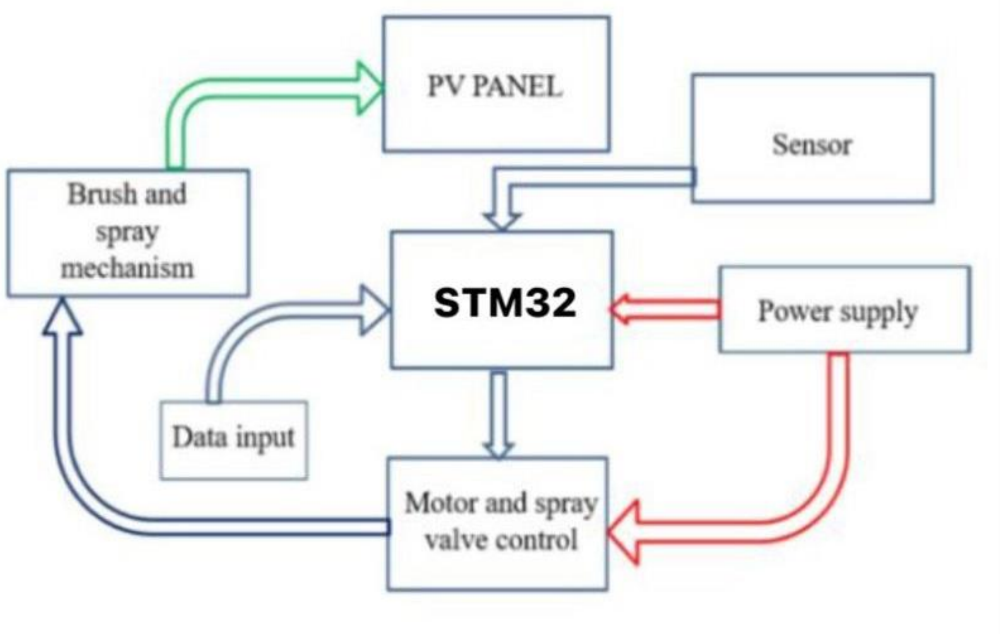

Figure 35 Methodology.

3.3.4 Working

At the beginning the motor starts moving and the wheels moves forward. As the motor starts, the spraying and the cleaning mechanism also starts. The robot moves forward and cleans the surface of the solar panel. When the robot reaches the end of the panel, the ultrasonic sensor detects the edge of the edge of the panel and stops the motor. Then the robot changes its direction by operating one pair of motors at a time. Once the direction is changed, the robot continues the cleaning process and moves forward further. The process continues and the entire surface of solar panel is cleaned.

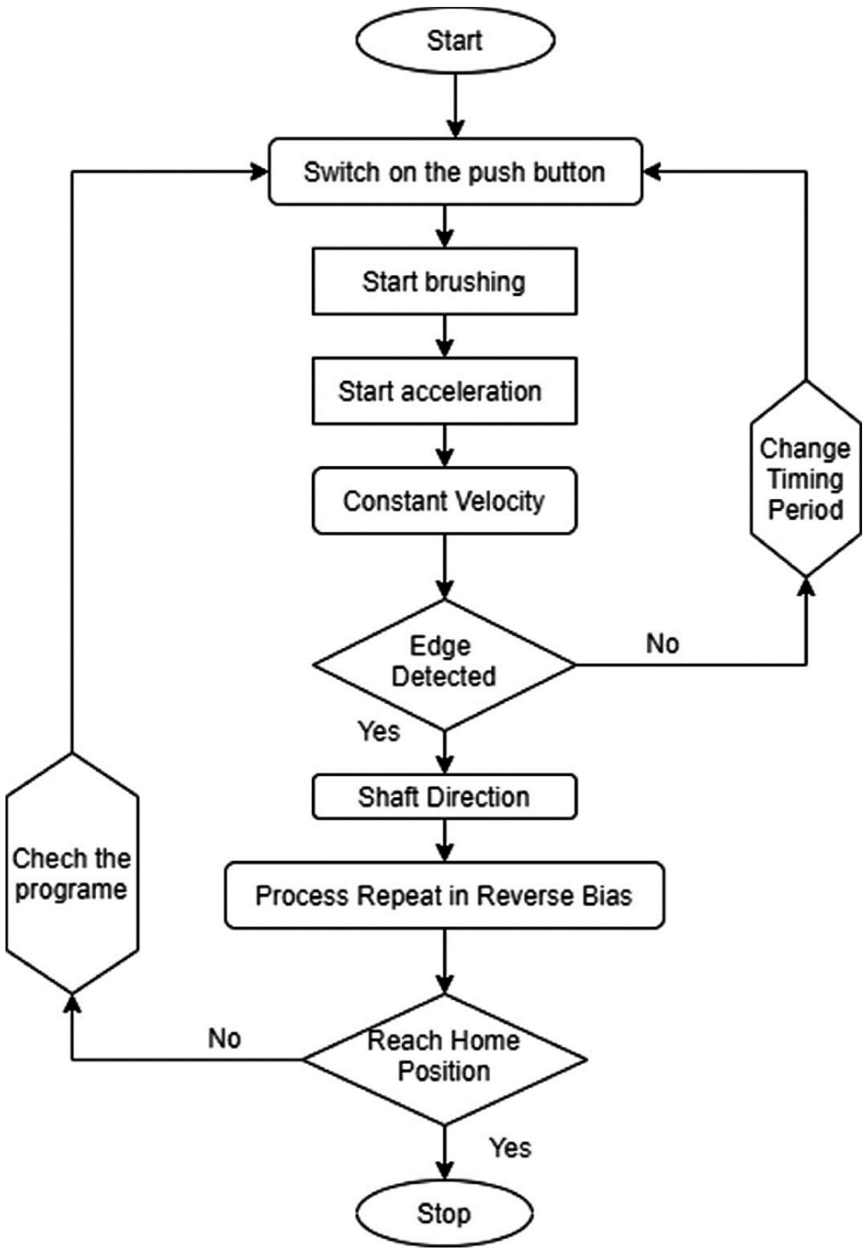

Figure 36 flowchart.

Chapter (4) Manufacturing process

4.1 Introduction

4.1.1 Objectives of the Production and Assembly

The primary objective of this chapter is to provide a comprehensive guide to the production and assembly of the SPAC system. This includes detailed information on material selection, design specifications, prototype development, fabrication of mechanical components, integration of electrical systems, and the overall assembly process. Additionally, this chapter will cover quality assurance measures, testing protocols, and solutions to common production challenges. By documenting each step of the production and assembly process, this chapter aims to ensure that the SPAC system can be manufactured and assembled efficiently, accurately, and to the highest standards.

4.1.2 Importance of Efficient and Accurate Manufacturing

Efficient and accurate manufacturing is crucial for the success of the SPAC system. High-quality production processes ensure that each component of the system functions correctly and reliably, minimizing the risk of malfunctions and maintenance requirements. Precision in manufacturing is essential to achieve the tight tolerances required for the seamless integration of mechanical and electrical components. Furthermore, efficient production techniques help to reduce costs and waste, making the SPAC system more economically viable and environmentally friendly.

Accurate manufacturing also plays a vital role in the scalability of the SPAC system. By establishing robust production protocols, the system can be manufactured consistently at larger scales to meet increasing demand. This scalability is essential for widespread adoption, enabling the benefits of the SPAC system to be realized across a broad range of solar energy installations. Ultimately, efficient and accurate manufacturing processes are fundamental to delivering a high-performance, reliable, and cost-effective automated cleaning solution that supports the growth of the solar energy sector.

4.2 Materials Selection

4.2.1 Criteria for Selecting Materials

Durability The materials used in the SPAC system must withstand prolonged exposure to various environmental conditions, including temperature fluctuations and moisture. Durability is essential to ensure that the system remains operational over extended periods without significant degradation.

Cost-effectiveness Cost is a crucial factor in material selection to ensure that the SPAC system remains economically viable. While high-performance materials are essential, they must also be cost-effective to keep the overall production and maintenance costs within budget. Balancing performance with affordability ensures that the system can be produced at scale and remains accessible to a broader market. This involves selecting materials that provide the necessary properties at a reasonable cost, such as using ST32 alloy for the framework instead of more expensive metals.

Availability The availability of materials is another critical criterion. The chosen materials must be readily available to avoid production delays and ensure a consistent supply chain. This involves selecting materials that are commonly used in the industry and have multiple suppliers. For example, ST32 is available material that can be sourced from various suppliers, reducing the risk of shortages and ensuring timely production.

Compatibility with Other Components Materials must be compatible with each other to ensure the seamless integration of all system components. This includes considering the thermal expansion coefficients, chemical compatibility, and mechanical properties of materials used in different parts of the system. For instance, the metal framework must be compatible with the fasteners and adhesives used to assemble the components, ensuring a secure and stable structure. Additionally, electrical components must be compatible with the housing materials to avoid electrical interference or damage.

4.2.2 List of Required Materials

Metal Framework The primary structure of the SPAC system is built from a ST32 alloy. This material is chosen for its strength and resistance to corrosion, making it ideal for outdoor use. The metal framework provides the necessary support for all other components and ensures the system's stability and durability.

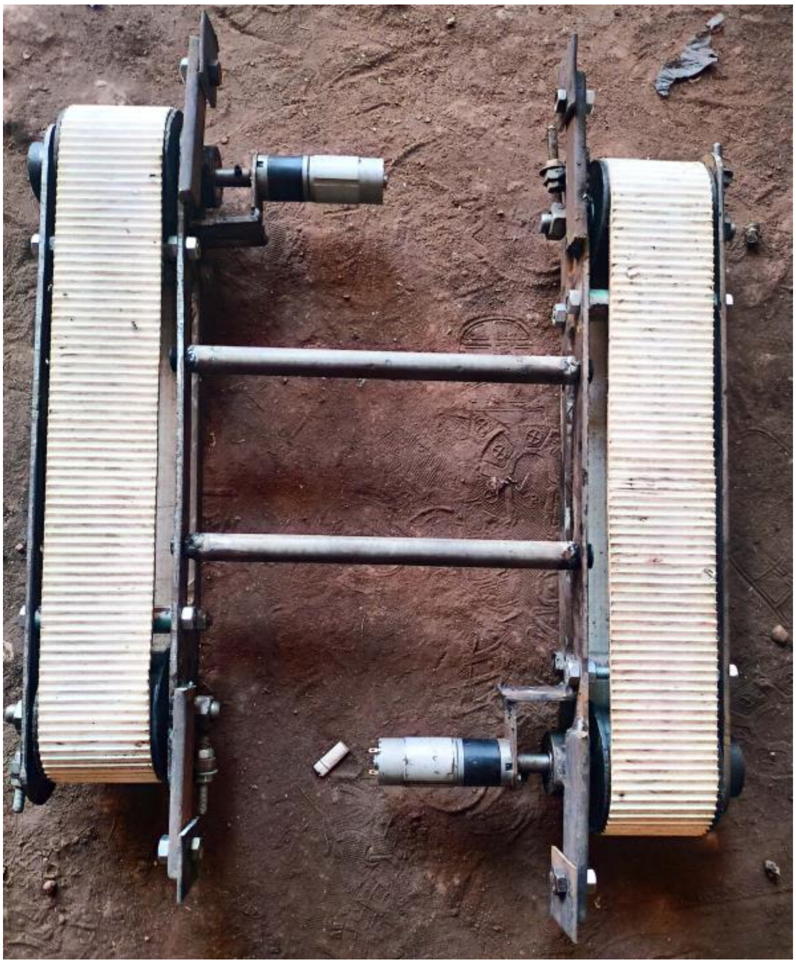

Figure 37 Robot Chassis

Belts The belts in solar panel cleaning robot are crucial for durability, efficiency, and minimal maintenance. High-quality materials like polyurethane or Kevlar ensure longevity, resistance to environmental factors, and energy efficiency. Proper material selection reduces operational costs and enhances the robots' overall performance and reliability. We chose rubber because its price is good and it sticks to the solar panel without slipping, even in the presence of water.

Figure 38 specimen of belts material

Figure 39 Robot belt

Brushes The cleaning mechanisms of the SPAC system, including brushes. These materials are selected for their effectiveness in removing dirt and debris from solar panels without causing scratches or damage. The brushes are designed to maintain their shape and performance over extended periods.

Figure 40 Robot brushes

Pulleys for Belts

The pulleys, essential for the movement and control of the SPAC system's belts, are made from raw Artilon. Artilon is chosen for its high strength, durability, and excellent wear resistance, making it suitable for continuous use in demanding outdoor environments. The pulleys facilitate smooth and efficient belt operation, contributing to the overall reliability and performance of the system.

Figure 41 Artilon Pulleys

Electrical Components (Sensors, Motors, Wires) The SPAC system includes various electrical components such as sensors, motors, and wiring. Ultrasonic Sensors are used to navigate the system across the solar panels. These sensors are typically made from durable plastics and metals that can withstand environmental conditions, See figure 35. The motors are divided into two parts, the part related to the belts and the part related to the brushes. As for the part related to the belts, (12V,57 rpm) which drive the cleaning mechanisms and the movement of the system, are selected for their efficiency and reliability, See figure 36. As for the part that concerns brushes, there are two 24V motors. Wiring is chosen for its conductivity and insulation properties, ensuring safe and efficient electrical connections throughout the system.

Figure 42 ultrasonic sensor

Figure 43 Belts Motor

Fasteners and Adhesives To assemble the various components of the SPAC system, a range of fasteners and adhesives are used. Stainless steel bolts and screws are chosen for their strength and resistance to corrosion, ensuring secure connections that can withstand environmental exposure, see figure 37. Industrial-grade adhesives are used to bond components where mechanical fasteners are not practical, providing strong and durable bonds that can endure the operational stresses of the system.

Figure 44 Stainless steel bolts and screws

By carefully selecting materials based on these criteria, the SPAC system achieves a balance of performance, durability, and cost-effectiveness, ensuring that it meets the demanding requirements of automated solar panel cleaning while remaining economically viable and reliable over the long term.

4.2.3 Properties and Benefits of Selected Materials

4.2.3.1 Strength and Resistance to Wear

The SPAC system is designed to operate in various environmental conditions, which necessitates the use of materials that are strong and resistant to wear. The material is chosen ensuring that the structure can withstand mechanical stresses and impacts during operation without deforming or failing.

4.2.3.2 Lightweight for Ease of Movement

Mobility is a critical feature of the SPAC system, allowing it to traverse the surface of solar panels efficiently. The use of lightweight materials ensures that the system remains easy to maneuver while maintaining structural integrity. The reduced weight not only enhances the system's operational efficiency but also minimizes the energy consumption required for movement, thereby extending the battery life and overall operational time.

4.2.3.3 Corrosion Resistance for Outdoor Use

Since the SPAC system is intended for outdoor use, it is crucial that all materials are resistant to corrosion. Additionally, components such as fasteners and connectors are made from stainless steel, which provides superior corrosion resistance compared to regular steel. The use of corrosion-resistant materials ensures the longevity and reliability of the SPAC system, reducing the need for frequent maintenance and replacements.

4.3 Design Specifications

4.3.1 Detailed Design Schematics

4.3.1.1 Technical Drawings and Blueprints

The SPAC system's design is meticulously documented through detailed technical drawings and blueprints. These documents provide comprehensive visual guides for the assembly and fabrication of the system. The technical drawings include multiple views (front, side, top) of the entire system as well as detailed sections of critical components. Each drawing is annotated with precise measurements, tolerances, and material specifications, ensuring that every part is manufactured to exact standards. These schematics serve as essential references throughout the production process, guiding engineers and technicians in the accurate construction of the SPAC system.

4.3.2 Functional and Technical Requirements

4.3.2.1 Cleaning Efficiency

The primary function of the SPAC system is to clean solar panels effectively. The design includes rotating brushes powered by electric motors, capable of removing dust, dirt, and debris without damaging the panels. The cleaning mechanisms are designed to operate at optimal speeds and pressures, ensuring thorough cleaning while minimizing wear on both the system and the solar panels.

4.3.2.2 Energy Consumption

Energy efficiency is a critical consideration in the design of the SPAC system. The system is powered by rechargeable batteries, with energy consumption minimized through the use of lightweight materials and efficient electric motors. The design also incorporates solar panels to recharge the batteries, allowing the system to operate autonomously for extended periods. Energy consumption is further reduced by incorporating energy-efficient control systems and sensors that optimize the cleaning process.

4.3.2.3 Durability and Maintenance

The SPAC system is designed for durability, with robust materials and construction techniques ensuring a long operational life. Components are selected and engineered to withstand the rigors of outdoor use and continuous operation. Maintenance requirements are minimized through the use of durable materials and components with low wear rates. The system is also designed for ease of maintenance, with accessible components and straightforward procedures for routine checks and repairs.

4.3.3 CAD Models and Technical Drawings

4.3.3.1 Visual Representation of Design

Computer-Aided Design (CAD) models provide a three-dimensional visual representation of the SPAC system. These models offer detailed insights into the spatial arrangement of components and the overall system layout. CAD models allow engineers to visualize the system in its entirety and make necessary adjustments to improve functionality and performance before actual production begins.

4.3.3.2 Detailed Component Views

The CAD models include detailed views of individual components and assemblies. Each component is modeled with precise dimensions and specifications, facilitating accurate manufacturing. Exploded views of assemblies are provided to illustrate the relationships between different parts and the sequence of assembly. These detailed component views are crucial for ensuring that each part fits correctly and functions as intended within the overall system.

By incorporating detailed design schematics, functional and technical requirements, and comprehensive CAD models, the SPAC system's design specifications provide a clear and precise roadmap for production and assembly, ensuring the system meets its performance, efficiency, and durability goals.

4.4 Prototype Development

4.4.1 Initial Prototype Creation

4.4.1.1 Steps in Creating the First Prototype

The development of the initial prototype of the SPAC system involves a series of well-defined steps designed to translate the conceptual design into a functional model. The process begins with the detailed study of the design schematics and CAD models to understand the overall structure and components. The initial steps include:

Material Procurement: all required materials, including ST32 for the framework, brushes, electrical components, fasteners, and adhesives.

Framework Assembly: Constructing the primary framework using ST32 profiles, cutting, and welding the pieces according to the design specifications.

Component Installation: Installing the cleaning mechanisms, including brushes, onto the framework. This involves precise mounting to ensure proper alignment and functionality.

Electrical Integration: Integrating the sensors, motors, and wiring into the framework. This step requires careful placement and secure connections to ensure reliable operation.

System Integration: Assembling all the components together, including attaching the control unit and power supply, to create a cohesive system.

Initial Testing: Conducting basic operational tests to check the movement of the system, the functionality of cleaning mechanisms, and the responsiveness of sensors.

4.4.1.2 Materials and Methods Used

The materials used in creating the first prototype are chosen based on the criteria of durability, cost-effectiveness, availability, and compatibility. The primary materials include:

ST32 Profiles: For the structural framework, providing strength and lightweight properties.

Rubber: For brushes and, ensuring effective cleaning without damaging solar panels.

Electrical Components: Including sensors, motors, and wires, sourced from reputable suppliers to ensure quality and reliability.

Stainless Steel Fasteners: For assembling various parts securely, chosen for their corrosion resistance.

The methods used in the prototype creation involve standard manufacturing techniques such as cutting, welding, drilling, and soldering. CAD software is used to guide the precise cutting and assembly of components, while electrical integration follows industry-standard wiring practices to ensure safety and efficiency.

4.4.2 Iterative Prototyping and Refinement

4.4.2.1 Testing and Feedback Cycles

Once the initial prototype is assembled, it undergoes a series of testing and feedback cycles aimed at identifying and resolving any issues. The process involves:

Initial Testing: Basic operational tests are conducted to ensure that the system moves correctly, the cleaning mechanisms operate as intended, and sensors are responsive.

Field Testing: The prototype is tested on actual solar panels to assess its cleaning efficiency and operational reliability under real-world conditions.

Data Collection: Performance data is collected during testing, including the effectiveness of cleaning, energy consumption, and any mechanical or electrical issues encountered.

Feedback Analysis: The collected data is analyzed, and feedback from testers and engineers is gathered to identify areas for improvement.

4.4.2.2 Modifications Based on Testing Results

Based on the feedback and performance data, modifications are made to the prototype to enhance its functionality and reliability. Common modifications include:

Adjusting Cleaning Mechanisms: Refining the alignment and pressure of brushes to improve cleaning efficiency.

Enhancing Durability: Reinforcing weak points in the framework and upgrading materials where necessary to increase durability.

Optimizing Electrical Systems: Improving sensor placement and wiring for better responsiveness and energy efficiency.

Streamlining Controls: Adjusting the control algorithms to optimize the system's movements and cleaning patterns.

This iterative process continues until the prototype meets the desired performance standards, ensuring that the final design is both effective and reliable.

4.4.3 Key Insights from Prototype Testing

4.4.3.1 Performance Data

The testing of the prototype yields valuable performance data that informs the final design. Key metrics collected include:

Cleaning Efficiency: Measured by the amount of dirt and debris removed from solar panels per cleaning cycle.

Energy Consumption: Monitored to ensure that the system operates efficiently and within the power limits of the onboard battery.

Operational Reliability: Assessed by the frequency and types of malfunctions or failures encountered during testing.

Durability: Evaluated by the wear and tear on components after prolonged use.

4.4.3.2 Lessons Learned and Improvements Made

The insights gained from prototype testing lead to several important lessons and subsequent improvements:

Enhanced Cleaning Mechanisms: Adjustments to the design and materials of brushes significantly improve cleaning performance without damaging the panels.

Optimized Power Management: Refining the power management system ensures longer operational periods and better energy efficiency.

Improved Structural Integrity: Reinforcements and material upgrades in the framework enhance the system's durability and resistance to environmental conditions.

Refined Control Algorithms: Modifying the control software improves the system's navigation and cleaning patterns, making it more effective and efficient.

Through this iterative process of prototyping, testing, and refinement, the SPAC system evolves from a conceptual design to a fully functional and reliable product, ready for large-scale production and deployment.

4.5 Mechanical Components Fabrication

4.5.1 Structural Framework Construction

4.5.1.1 Materials and Tools Used:

-ST32 sheets

- Steel rods

-Nuts and bolts

-Welding machine

-Cutting tools (e.g., hacksaw, grinder)

-Measuring tools (e.g., ruler, caliper)

-Drill and drill bits

4.5.1.2 Assembly Steps for the Framework:

1.Design and Measurement: We began by designing the structural framework for our solar panel cleaning system, making sure all measurements were accurate to fit around the solar panels perfectly.

2. Cutting ST32 Sheets and Steel Rods: Using cutting tools, we cut the ST32 sheets and steel rods as per our design specifications. Each piece was carefully measured and cut to the required length and shape.

3. Drilling Holes: Next, we drilled the necessary holes in the ST32 sheets and steel rods to allow for proper assembly. Aligning the holes correctly was crucial for the assembly process.

4. Welding: We then welded the steel rods together to create the base structure. Our goal was to ensure the welds were strong and stable enough to support the entire cleaning system.

5. Assembly: We attached the ST32 sheets to the welded steel rod structure using nuts and bolts. We made sure the framework was stable and properly aligned.

6. Inspection: Finally, we inspected the assembled framework for any structural weaknesses or misalignments, making necessary adjustments to ensure it was robust and fit around the solar panels correctly.

4.5.2 Production of Cleaning Mechanisms

4.5.2.1 Brush Selection:

- **Brush Selection**: We selected brushes with soft bristles to ensure they could effectively remove dust and dirt without scratching the solar panels.

4.5.2.2 Fabrication and Attachment Process:

1. Cutting Brushes to Size: We cut the brushes to the required dimensions, ensuring they would fit perfectly into our cleaning mechanism.

2. Attaching Brushes: The brushes were securely attached to the cleaning arms or rotating shafts using screws or adhesive, ensuring they were firmly in place and could move or rotate as needed.

3. Motor Installation: We installed motors to drive the movement of the, ensuring they were securely connected and operated smoothly.

4. Testing and Adjustment: We tested the cleaning mechanism to ensure the brushes functioned correctly. We made any necessary adjustments to the attachment points or motor connections to achieve optimal performance.

6. Integration with Control System: Finally, we integrated the cleaning mechanism with the system's control unit, enabling remote or automatic operation as required by our project specifications.

By following these steps, we were able to efficiently fabricate and assemble the mechanical components of our solar panel cleaning system, ensuring it performs reliably and effectively. Machining, Cutting, and Finishing Processes.

4.5.3 Techniques Used in Manufacturing Components:

1. Precision Cutting:

- **Description:** We used precision cutting techniques for ST32 sheets and steel rods to ensure all parts fit perfectly as per the design specifications. This involved using cutting tools such as hacksaws and grinders.
- **Tools Used:** Hacksaws, grinders, precision cutting saws.

2. Welding:
    - **Description:** The steel rods were welded together to form the base structure. We used high-quality welding techniques to ensure strong and durable joints.
    - **Tools Used:** Welding machine, welding rods, safety equipment.
3. Drilling:
    - **Description:** Accurate drilling was essential for creating holes for assembly. We used a drill and appropriate drill bits to make clean, precise holes in the ST32 sheets and steel rods.
    - **Tools Used:** Power drill, drill bits of various sizes, drill press for enhanced precision.
4. Adhesive Application:
    - **Description:** For attaching brushes and other components that required a strong but flexible hold, we used industrial-grade adhesives. This ensured the components stayed in place during operation but could be adjusted if needed.
    - **Tools Used:** Industrial-grade adhesives, applicators, clamps for setting.
5. Motor Installation:
    - **Description:** Installing the motors required precise alignment and secure mounting to ensure they could drive the cleaning mechanisms effectively. We used brackets and fasteners specifically designed for motor mounts.
    - **Tools Used:** Motor brackets, fasteners, alignment tools, torque wrench.
6. Cutting ("Parting Off"):
    - **Description:** This technique was used to separate parts from the raw material, ensuring components of the exact dimensions needed.
    - **Tools Used:** Parting tools, lathes.

Figure 45 Pulley during the parting off process

7. Knurling for Pulleys:
    - **Description:** Knurling was used to create textured surfaces on pulleys to enhance grip and traction for the belts.
    - **Tools Used:** Knurling tools, lathes.
8. Boring for Pulleys bearing:
    - **Description:** Boring was used to create precise internal diameters for pulleys, ensuring they fit perfectly onto shafts.
    - **Tools Used:** Boring tools, lathes.

Figure 46 bearing during boring process

9. Bushing:
    - **Description:** Bushings were used to reduce friction and wear between moving parts. They were carefully installed to ensure smooth operation of the rotating components.
    - **Tools Used:** Bushing installation tools, precision fitting tools.
10. Testing and Calibration:
    - **Description:** Post-assembly, each component underwent rigorous testing and calibration to ensure they operated as intended. This included running the motors, checking the movement of brushes, and ensuring all components worked together seamlessly.
    - **Tools Used:** Multimeter, calibration tools, test benches, software for system diagnostics.

Each of these techniques was crucial in ensuring the precision, durability, and reliability of our solar panel cleaning system. By employing these methods, we were able to create a robust and effective product that meets our design specifications and performance requirements.

4.5.4 Quality Control Measures:

1.Material Inspection: Before starting the manufacturing process, we thoroughly inspected all materials (ST32 sheets, steel rods, brushes) to ensure they met our quality standards. Any defective materials were rejected.

2.Dimensional Accuracy: Throughout the cutting and drilling processes, we continually checked the dimensions of each component against our design specifications using measuring tools like rulers and calipers.

3.Weld Quality: Each weld was inspected for strength and stability. We performed stress tests to ensure the welds could handle the operational loads without failing.

4.Assembly Integrity: After assembling the framework and attaching the components, we conducted a thorough inspection to ensure all nuts, bolts, and adhesive bonds were secure and properly aligned.

5.Functional Testing: Once the mechanical components were assembled, we ran functional tests to check the operation of the cleaning mechanisms. This included verifying the rotation of brushes, the movement of, and the performance of motors.

6.Operational Stress Testing: We simulated operational conditions to test the durability and reliability of the system. This included running the system for extended periods to ensure it could withstand prolonged use without any issues.

7.Final Inspection: Before finalizing the product, we conducted a comprehensive inspection covering all aspects of the system. This ensured that every component met our quality standards and the system was ready for deployment.

By employing these manufacturing techniques and stringent quality control measures, we ensured that our solar panel cleaning system was built to high standards, capable of delivering reliable and effective performance.

4.6 Electrical Systems Integration

The electrical systems integration of our solar panel cleaning system involves the careful installation and integration of sensors, actuators, and the control system. This ensures the system operates efficiently and effectively.

4.6.1 Installation of Sensors

4.6.1.1 Types of Sensors Used:

- **Ultrasonic Sensors**: These sensors measure distances by emitting sound waves and collecting the returning echoes. They help in navigation and obstacle detection, ensuring the cleaning robot operates smoothly.
- **Infrared (IR) Sensors**: These sensors detect objects and measure distances using infrared light. They are used for close-range detection and to avoid collisions.
- **Gyroscope Sensors**: These sensors measure the robot's orientation and angular velocity, aiding in stable navigation and precise movement control.

4.6.1.2 Placement and Installation Steps:

1. Ultrasonic Sensors Placement:
    - **Location**: Position the ultrasonic sensors at the front and sides of the robot for comprehensive obstacle detection.
    - **Installation**: Attach the sensors to the robot frame with brackets. Connect each sensor to the servo motors for directional adjustment and to the ESP32 microcontroller for processing the distance measurements.
2. Infrared (IR) Sensors Placement:
    - **Location**: Install the IR sensors on the front and rear sections of the robot for enhanced obstacle detection.
    - **Installation**: Secure the IR sensors using mounting brackets. Ensure they are connected to the ESP32 microcontroller for signal processing and integration with the robot's control system.
3. Gyroscope Sensors Placement:
    - **Location**: Place the gyroscope sensor centrally on the robot to accurately measure its orientation.
    - **Installation**: Mount the gyroscope sensor on a stable part of the robot frame. Connect it to the ESP32 microcontroller for real-time orientation data processing and control feedback.

4.6.2 Integration of Actuators

Motor Selection and Installation:

- **Motor Selection:** We use four DC motors; two for the gliders that enable the robot's movement and two for driving the cleaning brushes ,see Table 3.

Table 3 Decision matrix for motors

			Weighing scale 1 → 10		
			Types		
			DC Motor	Stepper Motor	Servo Motor
Priority Scale 1 → 5	Criteria	Rating ↑~ High ↓~ Low			
5	Cost	↓	10	7	6
5	Torque	↑	10	7	6
4	Speed	↑	8	7	9
5	Control	↑	7	9	8
1	Size	↓	7	7	8
Total			174	150	144

- **Installation Steps:**

1. **Mount the Motors:** Attach the DC motors to the designated motor mounts on the robot chassis using screws and brackets.
2. **Connect to the Motor Driver:** Link the motors to the motor driver circuits, ensuring secure and stable connections.
3. **Wiring:** Connect the motor driver to the ESP32 microcontroller to enable control over motor operations.

4.6.3 4.7 Control System Integration

ESP32 Microcontroller: The ESP32 microcontroller serves as the brain of the system, managing inputs from sensors and controlling the actuators. It was chosen to replace the STM32 for its advanced features, including integrated Wi-Fi and Bluetooth, facilitating remote control and communication with the cleaning robot.

Bluetooth: This module is installed to enable remote control and communication with the cleaning robot. They are connected to the ESP32 microcontroller for seamless integration and operation.

Power Supply: The system uses two batteries to provide adequate power for all components: one 12V battery powers the belt motors, and one 24V battery powers the brushes.

Switches: Switches are implemented to control the power supply to different components of the robot, enhancing operational flexibility and safety.

Operation in Auto Mode:

1. **Initial Positioning:** Place the robot on the edge of the solar panel.
2. **Defined Distance Movement:** The robot moves a predefined distance along the solar panel.
3. **Direction Check:** The robot uses the gyroscope sensor to check its angle and determine the direction.
4. **Mark Detection:** An IR sensor detects a mark at the end of the solar panel, signaling the robot to return to its home position.
5. **Navigation and Cleaning:** The robot adjusts its path based on sensor data to ensure comprehensive cleaning of the solar panel surface and returns to the starting point upon completing the cleaning cycle.

4o

4.7 Wiring and Control Systems Configuration

4.7.1.1 Electrical Schematics:

- **Schematic Design:** Create detailed electrical schematics showing the connections between the ESP32 microcontroller, sensors, motor drivers, motors, and power supply.
- **Components:** Include all components like the dust sensor, ultrasonic sensors, DC motors, motor drivers, and communication modules.

4.7.1.2 Wiring Procedures and Safety Measures:

1. **Wiring Procedures:**
    - **Connect Sensors:** Wire the dust sensor and ultrasonic sensors to the ESP32 microcontroller, ensuring proper signal transmission.

- **Motor Connections:** Connect the DC motors to the motor drivers and link the motor drivers to the microcontroller.
- **Power Supply:** Connect the rechargeable lithium battery to the power inputs of the microcontroller, motors, and other components.
- **Communication Modules:** Ensure proper wiring of the Bluetooth and Wi-Fi modules to the microcontroller for remote control.

2. **Safety Measures:**
   - **Insulate Wires:** Use heat shrink tubing or electrical tape to insulate exposed wires and prevent short circuits.
   - **Secure Connections:** Ensure all connectors and terminals are securely fastened to avoid loose connections.
   - **Power Management:** Verify that the power supply is adequate for all components to prevent overloading and overheating.

4.8 Assembly Process

4.8.1.1 Step-by-Step Assembly Instructions

1. **Frame Assembly:**
   - Assemble the structural framework using ST32 sheets and steel rods.
   - Secure the joints with welding or bolts, ensuring stability and strength.
2. **Motor Installation:**
   - Mount the DC motors onto the chassis.
   - Connect the motors to the motor drivers and microcontroller as per the wiring schematic.
3. Sensor Installation:
   - Placement: Position the ultrasonic sensors, IR sensors, and gyroscope sensor in their designated positions on the robot.
   - Connection: Connect the ultrasonic sensors, IR sensors, and gyroscope sensor to the microcontroller for signal processing and integration with the robot's control system.

Brush Attachment:

- Attach the cleaning brushes to the designated motor shafts.
- Ensure the brushes are securely fastened and aligned for optimal cleaning.

4. **Water System Integration:**
   - Install the water tank, pump, filters, valves, and nozzles.

- Connect the water system to the power supply and control unit.

5. **Electrical Connections:**
    - Follow the wiring schematic to connect all electrical components.
    - Double-check all connections for accuracy and security.
6. **Testing and Calibration:**
    - Power up the system and run initial tests to verify sensor functionality and motor operations.
    - Calibrate the sensors and motors as needed to ensure precise operation.

4.8.2 Required Tools and Equipment

- **Screwdrivers and Wrenches:** For assembling the frame and securing components.
- **Drill and Drill Bits:** For creating holes in the frame for component installation.
- **Soldering Iron and Solder:** For making electrical connections.
- **Wire Strippers and Cutters:** For preparing wires for connections.
- **Heat Shrink Tubing and Electrical Tape:** For insulating electrical connections.
- **Multimeter:** For testing electrical circuits and verifying connections.
- **Welding Equipment:** For assembling the frame (if welding is used).

By following these detailed instructions and utilizing the specified tools and equipment, the assembly process of our solar panel cleaning system can be carried out efficiently, ensuring a reliable and effective final product.

Chapter (5): Product Testing

This chapter provides a detailed overview of the testing processes implemented to verify that our solar panel cleaning system meets its design objectives and adheres to engineering standards. Each component and subsystem was rigorously tested to ensure functionality, reliability, and efficiency.

5.1 Verification of the Objectives of the Project

The primary objective of the project is to create an automated solar panel cleaning system that efficiently cleans solar panels, thereby improving their performance and longevity. The verification process involves testing each critical component to ensure it performs as expected within the integrated system.

Key Objectives:

- Ensure the cleaning mechanism effectively removes dirt and debris from solar panels.
- Verify that the system operates autonomously with minimal manual intervention.
- Confirm the reliability and durability of the components under various environmental conditions.

5.1.1 DC Motor Testing

Objective:

To verify the performance and reliability of the DC motors used for the glider movement and brush rotation.

Testing Procedures:

1. Initial Inspection:

- Check the motors for any physical defects or damages.
- Ensure proper mounting and alignment with the glider and brush mechanisms.

2. Operational Testing:

- Connect the motors to the motor driver and control them via the STM32 microcontroller.

- Run the motors at various speeds to observe their performance.
- Measure the torque and speed under different loads.

3. Durability Testing:

- Operate the motors continuously for an extended period to assess their durability.
- Monitor for overheating, unusual noises, or vibrations.

Results:

- The DC motors operated smoothly at various speeds.
- They provided adequate torque for both glider movement and brush rotation.
- The motors showed no signs of overheating or significant wear after prolonged use.

5.1.2 ESP32 Microcontroller Testing

Objective:

To ensure the ESP32 microcontroller accurately processes sensor data and controls the actuators.

Testing Procedures:

1. Connection Verification:

- Verify all sensor and actuator connections to the microcontroller.
- Check the communication with the Bluetooth and Wi-Fi modules.

2. Functionality Testing:

- Upload test code to theESP32 to ensure it reads sensor data correctly.
- Test the control commands sent to the motors and actuators.

3. Integration Testing:

- Integrate the ESP32 with the full system and run comprehensive tests to check the coordination between sensors and actuators.

Results:

- The ESP32 microcontroller successfully reads data from all connected sensors.
- It effectively controlled the DC motors and other actuators as per the programmed commands.
- The integration with Bluetooth and Wi-Fi modules was seamless, allowing for remote control and monitoring.

5.1.3 Water System Testing

Objective:

To verify the functionality and efficiency of the water system, including the pump, tank, filters, valves, and nozzles.

Testing Procedures:

1. Component Inspection:

- Inspect the water tank, pump, filters, valves, and nozzles for any defects or leaks.
- Ensure all components are properly connected and secured.

2. Pressure Testing:

- Run the water pump to check the pressure output.
- Adjust the valves to regulate the water flow to the nozzles.

3. Operational Testing:

- Activate the water system and observe the spray pattern from the nozzles.
- Ensure the water reaches all parts of the solar panel surface.

4. Filter Efficiency Testing:

- Test the filters' ability to remove impurities from the water.
- Monitor the system for any blockages or reduced flow.

Results:

- The water pump provided consistent pressure, and the valves effectively regulated the flow.
- The nozzles delivered a uniform spray pattern, covering the entire panel surface.
- Filters efficiently removed impurities, ensuring clean water application.

5.1.4 Brush System/Mechanism Testing

Objective:

To test the effectiveness and reliability of the brush mechanism in removing dirt and debris from the solar panels.

Testing Procedures:

1. Physical Inspection:

- Check the brushes for proper alignment and secure attachment to the motor shafts.
- Inspect the bristles for any damage or wear.

2. Operational Testing:

- Run the brush motors to observe the rotation and contact with the panel surface.
- Test the cleaning performance by applying dirt and debris to a test panel and operating the brushes.

3. Durability Testing:

- Operate the brushes for an extended period to assess wear and tear.
- Monitor for any decrease in cleaning efficiency or motor performance.

Results:

- The brushes rotated smoothly and maintained consistent contact with the panel surface.
- They effectively removed dirt and debris, restoring the panel's cleanliness.
- The brushes showed minimal wear after prolonged use, indicating good durability.

5.2 Verification of the Applied Engineering Standards

Objective:

To ensure that the project adheres to the relevant engineering standards for safety, reliability, and performance.

Standards Applied:

- **Electrical Safety Standards:** Ensured proper insulation, grounding, and secure connections to prevent electrical hazards.

- **Mechanical Standards:** Verified that all mechanical components are robust and can withstand operational stresses.

- **Environmental Standards:** Tested the system's resistance to weather conditions, such as rain, dust, and temperature variations.

Verification Procedures:

1. Safety Inspections:

- Conduct thorough inspections of electrical and mechanical connections.
- Implement necessary safety measures, such as circuit protection and fail-safes.

2. Performance Testing:

- Evaluate the system's performance under various operating conditions.
- Ensure consistent cleaning efficiency and system reliability.

3. Compliance Audits:

- Conduct audits to verify adherence to the specified engineering standards.
- Document all compliance measures and results.

Results:

- The system meets all relevant electrical and mechanical safety standards.
- It performs reliably under various environmental conditions.
- All components and subsystems comply with the applicable engineering standards, ensuring a safe and effective final product.

Conclusion

The rigorous testing procedures implemented for each component of our solar panel cleaning system have confirmed that the design meets its objectives. The system operates efficiently, safely, and reliably, providing an effective solution for maintaining clean and efficient solar panels. By adhering to engineering standards and thoroughly testing each subsystem, we ensure the system's durability and performance, making it a viable product for widespread use.

Chapter (6) Cost Analysis

This chapter delves into a comprehensive cost analysis of our solar panel cleaning system (SPAC), providing detailed estimates for prototyping, production, and customer savings. Additionally, we compare our project's cost-effectiveness with other existing solar panel cleaning systems.

6.1 Prototyping Cost Estimate

The prototyping phase involves developing a functional model of the solar panel cleaning system to test and refine the design before moving into full-scale production. Below is the breakdown of the costs associated with creating the prototype, Table 3:

Table 3 Prototyping Cost <page 1 of 2>

O	Component	Description	Cost
	ESP32	The microcontroller we use to control the system	350
	DC Motor	4 DC motors, 2 for gliders that make the robot move, and 2 for the cleaning brushes.	1000*4 =4000
	Bluetooth Module	Bluetooth module that allows us to remotely control the robot.	300
	Rechargeable Lithium Battery	Battery that provides power for motors and control unit.	2*1500 =3000
	Water Pump	Pump to raise the pressure of water for wet cleaning.	500
	Motor Driver	Integrated circuit chip that controls motors in autonomous robots and embedded circuits.	200*4= 800
	Water Tank	Water tank that holds the water for wet cleaning.	200
	Filter,Valves, and Nozzles	Filters to purify water from impurities, and nozzles that will be over the brushes and used in wet cleaning.	3500
	Relays	For motor.	800
	Fabrication	The fabrication of the robot and design.	1000

Table 3 Prototyping Cost <page 2 of 2>

	Component	Description	Cost
1	Cleaning Brushes	2 brushes, in front and back.	2*4=800
2	Lights for Night Cleaning	Lights for night cleaning.	4*100=400
3	Dust Sensor	Dust sensor that senses the accumulated dust over the panel and takes decisions based on that.	380
4	Ultrasonic Sensors with Servo Motor	Electronic device which measures distances by sending out sound waves and collecting the returning echoes.	2*250=500
5	Belt	Loop of flexible material used to link the two rotating shafts mechanically.	800
6	Wi-Fi Module	To control the robot remotely by Wi-Fi connection.	300
	Total Prototyping Cost: 26,630 EGP		

6.2 Production Cost

Transitioning from prototyping to full-scale production involves economies of scale, which typically reduces the cost per unit. However, initial investments in production tools, molds, and assembly lines must be considered.

Here's an estimate of production costs:

- Mass Production of Components:

- Bulk purchasing of DC motors, batteries, and sensors could lead to a 10-20% reduction in unit cost.

- Manufacturing costs for components like the frame and brushes would decrease due to optimized fabrication processes.

- Labor and Overhead:

- Assembly line setup, quality control, and labor costs must be factored in. These might initially be high but will decrease as processes become more efficient.

- Packaging and Shipping:

- Costs for packaging materials and shipping logistics must be considered, especially for international distribution.

Based on these considerations, the estimated production cost per unit could be reduced to approximately (20,000 EGP) after accounting for bulk discounts and streamlined production processes.

6.3 Customer Savings

One of the key selling points of our solar panel cleaning system is the cost savings it offers to customers. Regular cleaning of solar panels is crucial for maintaining their efficiency and maximizing energy output. Manual cleaning or hiring cleaning services can be costly and inconsistent.

Cost Comparison:

- Manual Cleaning Services: Typically, manual cleaning services charge around 500-1000 EGP per cleaning session, with recommended cleanings occurring at least twice a month. This results in an annual cost of approximately 12,000-24,000 EGP.

- Our Automated System: Assuming a one-time investment of 26,630 EGP for the prototype, and considering that production units would be cheaper, customers would recoup their investment within one to two years. Moreover, the automated system can operate more frequently, ensuring optimal panel efficiency without additional labor costs.

Long-Term Savings:

- Increased Efficiency: Clean panels can increase energy output by 15-25%, directly translating into higher savings on electricity bills.

- Reduced Maintenance Costs: Automated systems reduce the wear and tear associated with manual cleaning, leading to lower maintenance costs over time.

Comparison with Other SPAC Systems

Our solar panel cleaning system stands out in the market due to its cost-effectiveness and robust design. Compared to other SPAC systems that may cost upwards of 30,000-40,000

EGP, our system offers similar functionality at a reduced cost. This is achieved through careful selection of components and efficient design practices.

Other systems might offer additional features such as advanced AI for predictive maintenance or self-repair capabilities, but these often come at a significantly higher cost. Our system focuses on the core functionality of effective and reliable cleaning, providing excellent value for money.

Conclusion

The cost analysis highlights the affordability and efficiency of our solar panel cleaning system. With a prototyping cost of 26,630 EGP and potential production cost reductions, the system is positioned to offer substantial savings to customers. By maintaining clean solar panels, customers benefit from increased energy output and reduced maintenance expenses, making our system a cost-effective solution in the competitive SPAC market.

Chapter (7) Summary

7.1 Overall Evaluation of the Design

Our solar panel cleaning system project aimed to develop an efficient, cost-effective, and reliable solution to maintain the cleanliness of solar panels, thereby enhancing their efficiency and energy output. The design process involved careful selection of components, rigorous testing, and thorough quality control measures to ensure the system's effectiveness and durability.

Key Achievements:

- Effective Cleaning Mechanism: The use of soft brushes, efficient water pumps, and filters ensures thorough cleaning without damaging the solar panels.
- Automated Operation: Integration of STM32 microcontroller, Bluetooth, and Wi-Fi modules enables remote and automated control, reducing the need for manual intervention.
- Cost Efficiency: With a prototyping cost of 26,630 EGP and potential reductions in production costs, our system provides a cost-effective alternative to manual cleaning services and other SPAC systems in the market.

The design successfully balances performance and cost, making it a viable option for both small-scale and large-scale solar panel installations.

7.2 Suggestions for Improvement / Lessons

Throughout the development of our solar panel cleaning system, several areas for potential improvement were identified:

- **Enhanced Sensors and AI Integration**: Incorporating advanced sensors and artificial intelligence could enhance the system's ability to detect dirt levels and predict maintenance needs, further optimizing cleaning schedules.
- **Energy Efficiency**: While the system is powered by rechargeable lithium batteries, exploring alternative energy sources like small solar panels on the robot itself could improve energy efficiency and autonomy.

- Durability and Weather Resistance: Future versions of the system could benefit from enhanced durability and weather resistance, ensuring consistent performance in varying environmental conditions.

Lessons Learned:

- Importance of Prototyping: Building a prototype was crucial for identifying design flaws and making necessary adjustments before moving to full-scale production.

- Quality Control: Rigorous quality control measures are essential to ensure the reliability and longevity of the system.

- Cost Management: Effective cost management from the prototyping phase through to production is vital for maintaining the project's financial viability.

7.2.1 Wisdom to Pass On

From our experience developing this project, several key pieces of wisdom emerge:

- Iterative Design: Embrace an iterative design process. Initial designs are seldom perfect, and continuous refinement is necessary to achieve the best results.
- Collaboration: Effective collaboration among team members with diverse expertise is critical. Leveraging each person's strengths leads to a more robust and innovative final product.
- User-Centric Approach: Always keep the end-user in mind. Designing with the user’s needs and convenience as a priority ensures the final product is practical and widely acceptable.
- Sustainability: Consider the environmental impact of your design. Aim for solutions that not only solve the immediate problem but also contribute positively to the environment.

Conclusion

Our solar panel cleaning system represents a significant advancement in maintaining the efficiency of solar energy systems. By providing an automated, cost-effective, and reliable cleaning solution, we address a critical need in the renewable energy sector. The insights gained from this project will guide future developments, ensuring ongoing improvements and innovations in solar panel maintenance technologies.

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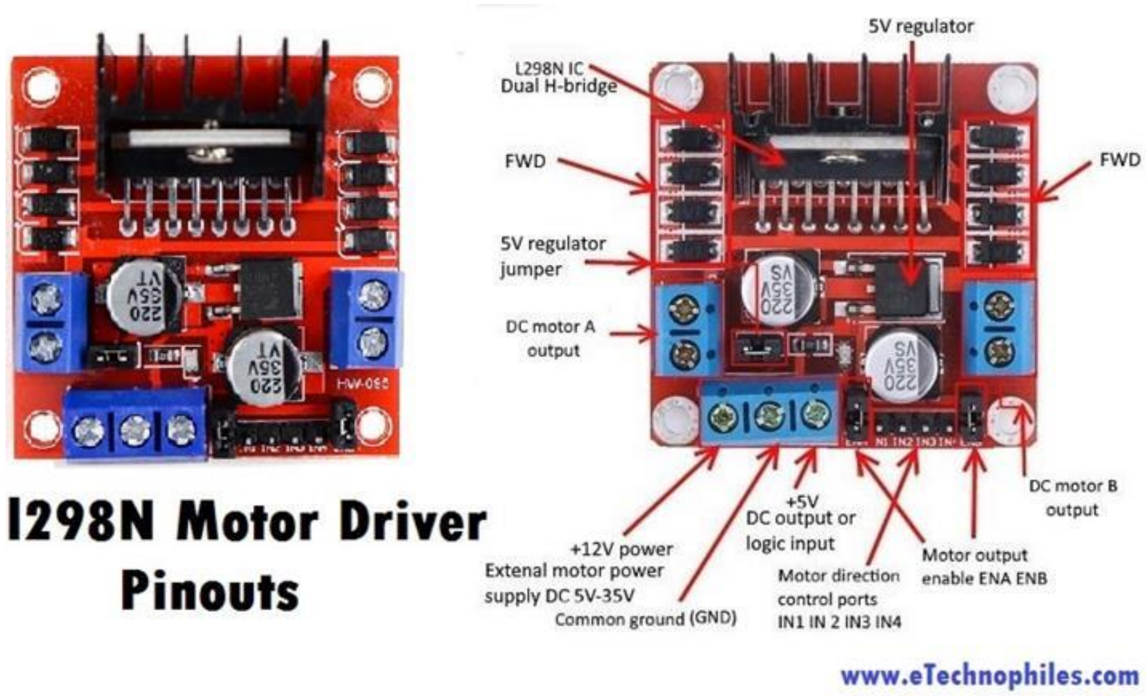
APPENDIX A: Components specifications



Dual H Bridge Motor Driver

L298N motor driver IC

Drives up to 2 bidirectional DC motors

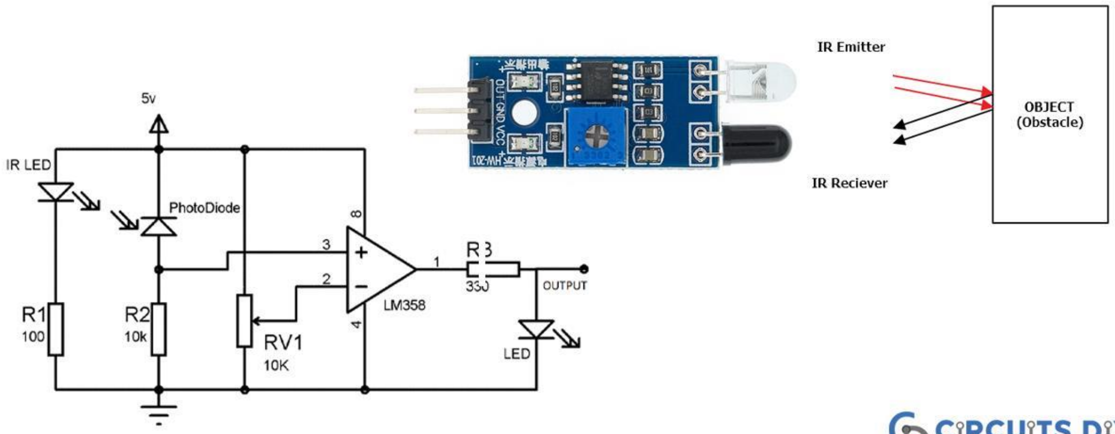
Integrated 5V power regulator

5V – 35V drive voltage

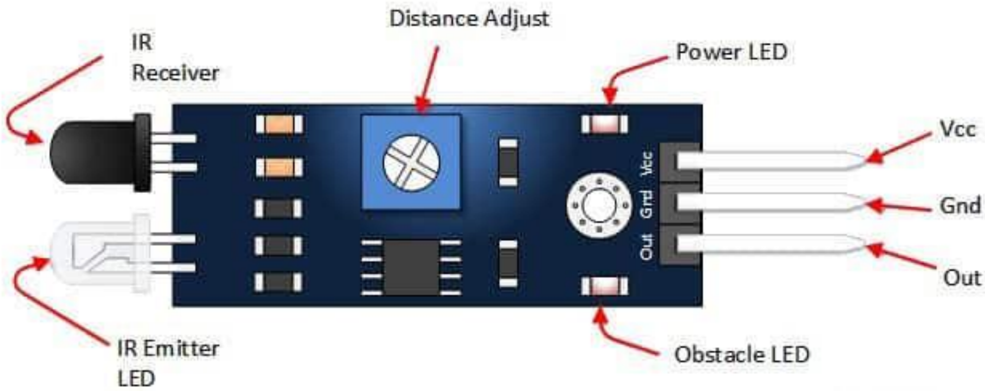
2A max drive current

	Technical Specifications
Double H Bridge Drive chip	L298N
Logical Voltage	5V
Drive Voltage	5V -35V
Logical Current	0-36 mA
Driver Current	2A (Max Single bridge)
Max Power	25 W
Dimension	43 * 43 * 26 mm

IR Sensor Module Circuit



CIRCUITS DIY
PROJECTS | TUTORIALS | CIRCUITS | DATASHEETS

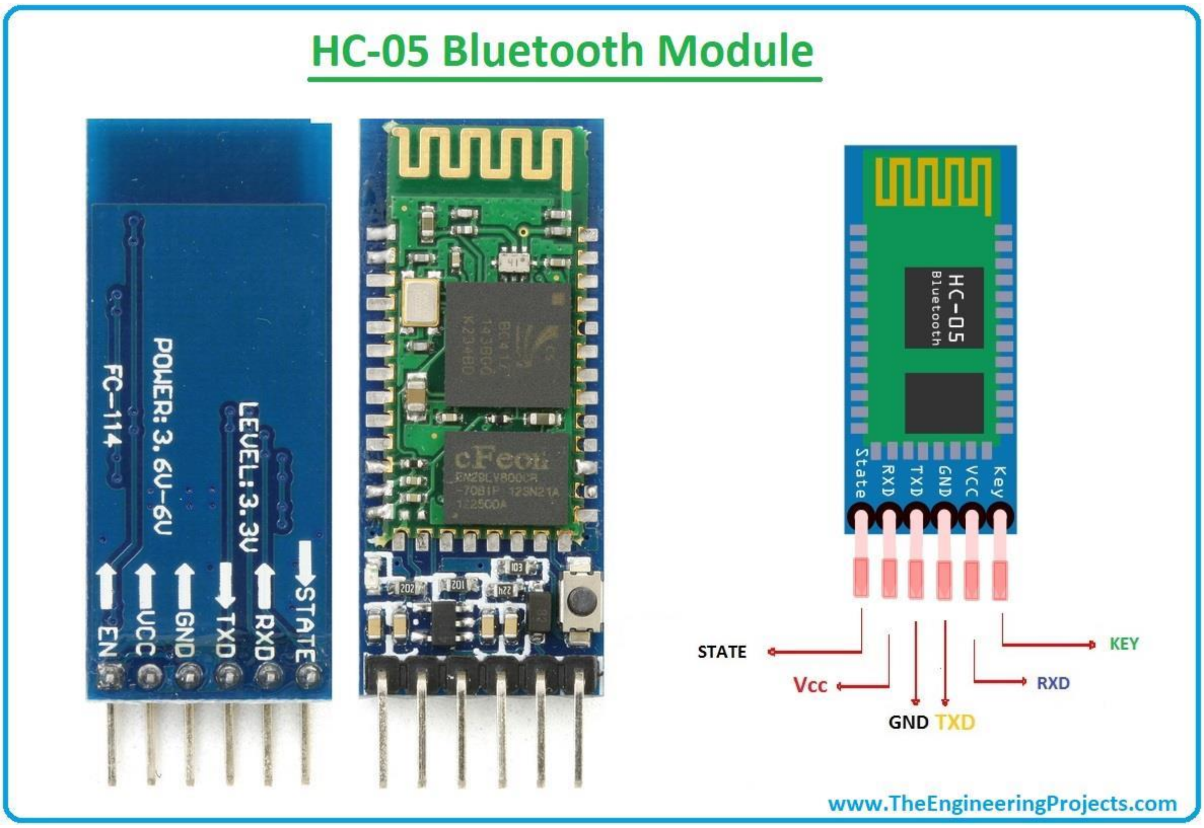


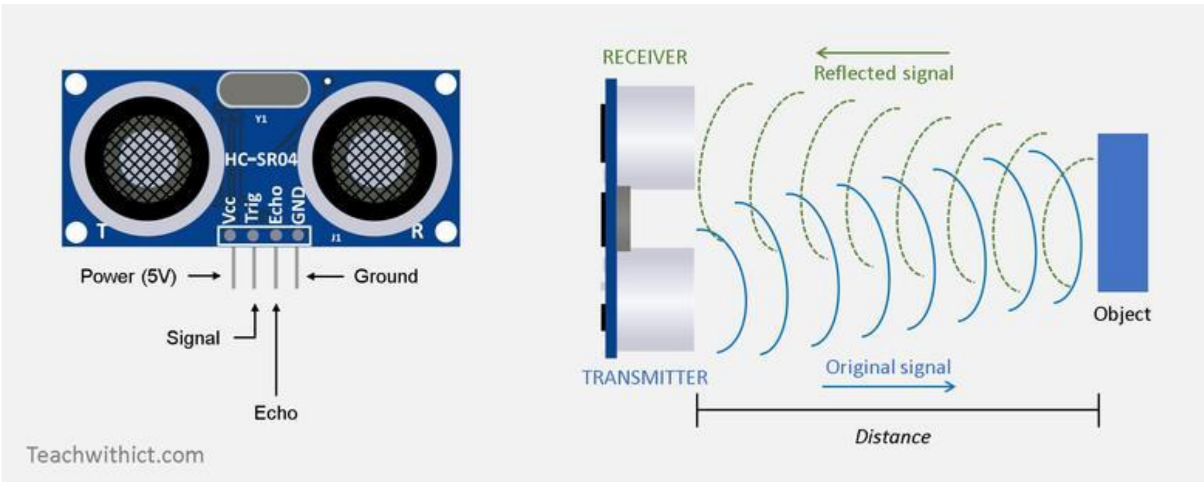
Pin Description

Vcc	3.3 to 5 Vdc Supply Input
GND	Ground Input
Out	The output that goes low when an obstacle is in range
Power LED	Illuminates when power is applied
Obstacle LED	Illuminates when an obstacle is detected
IR Emitter	Infrared emitter LED
IR Receiver	The infrared receiver that receives signal transmitted by Infrared emitter.

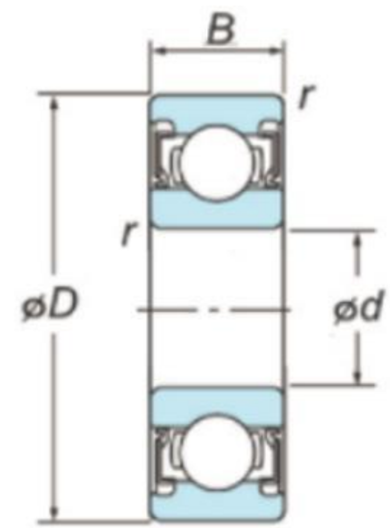
Specifications

Board Size	3.2 x 1.4cm
Working voltage	3.3 to 5V DC
Operating voltage	3.3V: ~23 mA, to 5V: ~43 mA
Detection range	2cm – 30cm (Adjustable using potentiometer)
Active output level	The output is “0” (Low) when an obstacle is detected


HC-05 Bluetooth Module
POWER: 3.6V-6V
FC-114
LEVEL: 3.3V
EN
VCC
GND
TXD
RXD
STATE
HC-05 Bluetooth
State
RXD
TXD
GND
VCC
Key
STATE
Vcc
GND
TXD
RXD
KEY
www.TheEngineeringProjects.com


HC-SR04
Vcc
Trig
Echo
GND
T
R
Power (5V)
Ground
Signal
Echo
Teachwithict.com
RECEIVER
Reflected signal
TRANSMITTER
Original signal
Object
Distance

Products name	C&U brand high quality metric miniature ball bearing 624rs 624 2rs 624z 624zz 624 small bearing
Brand name	neutral brand.imported brand or be customized to the customer's brand
Series	624ZZ .624 2RS.624 RZ.624Z.624 RS
ID size	4mm-13mm-5mm
material	Stainless steel.Gcr15.carbon steel
Precision	PO P6 P5 P4
Sealing	Open, Z, ZZ, RZ,2RZ,RS, 2RS
Quality standard	ISO9001:2000 standard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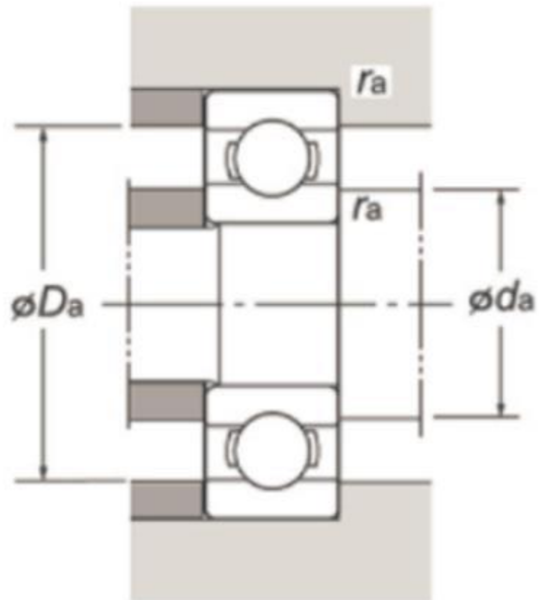
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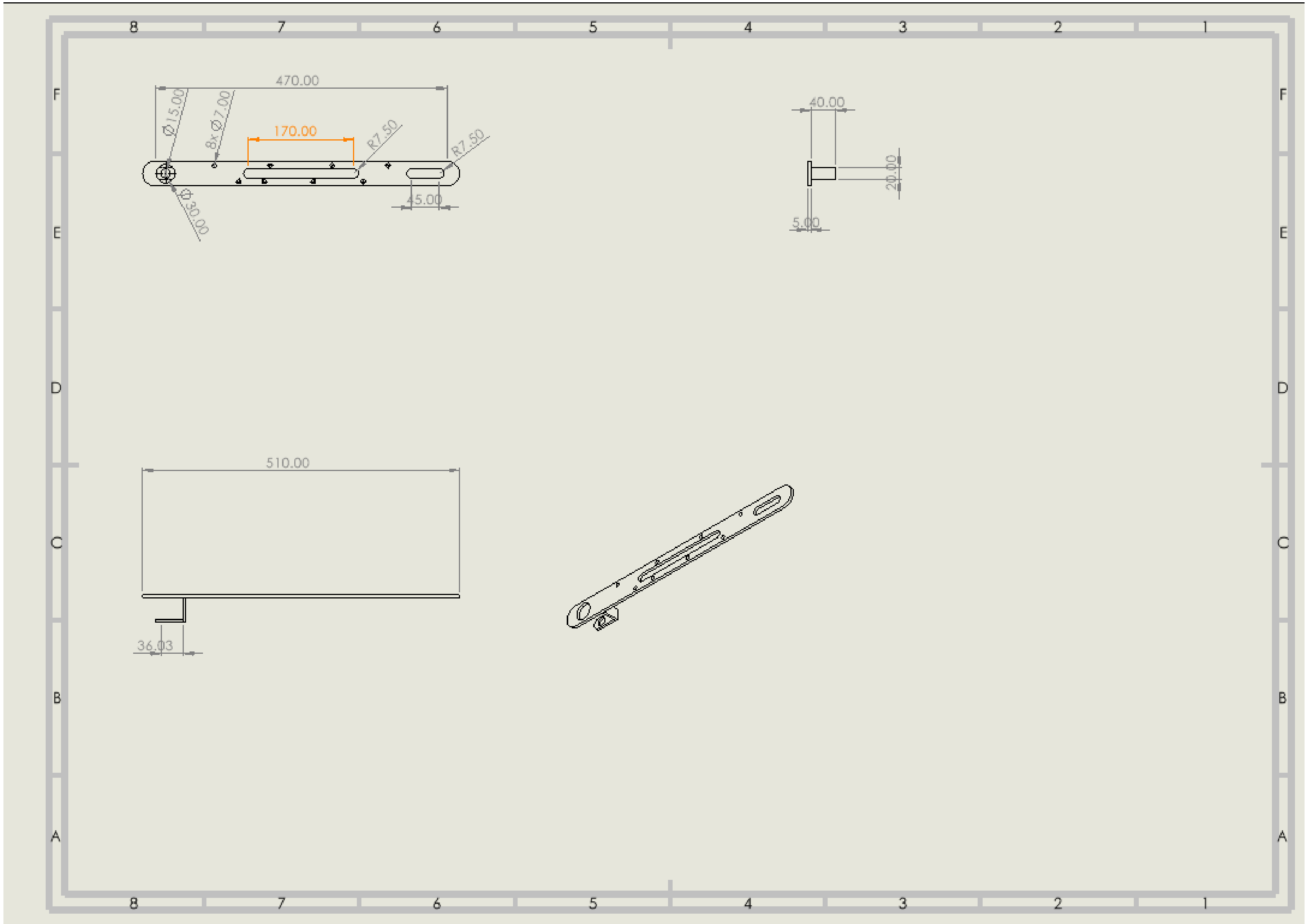
APPENDIX B: ENGINEERING DRAWINGS

The engineering drawings for the robotic system are shown in the following pages



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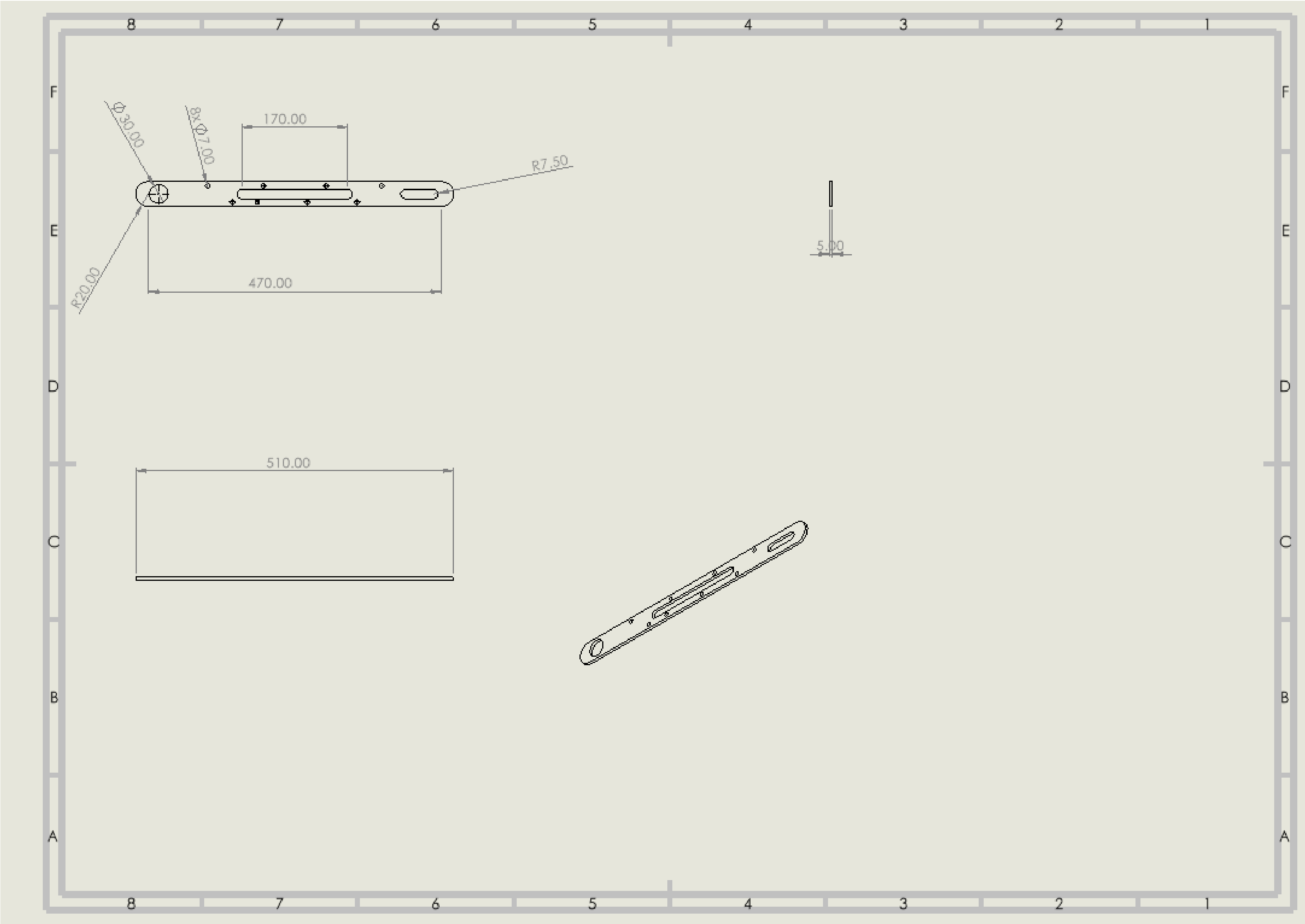

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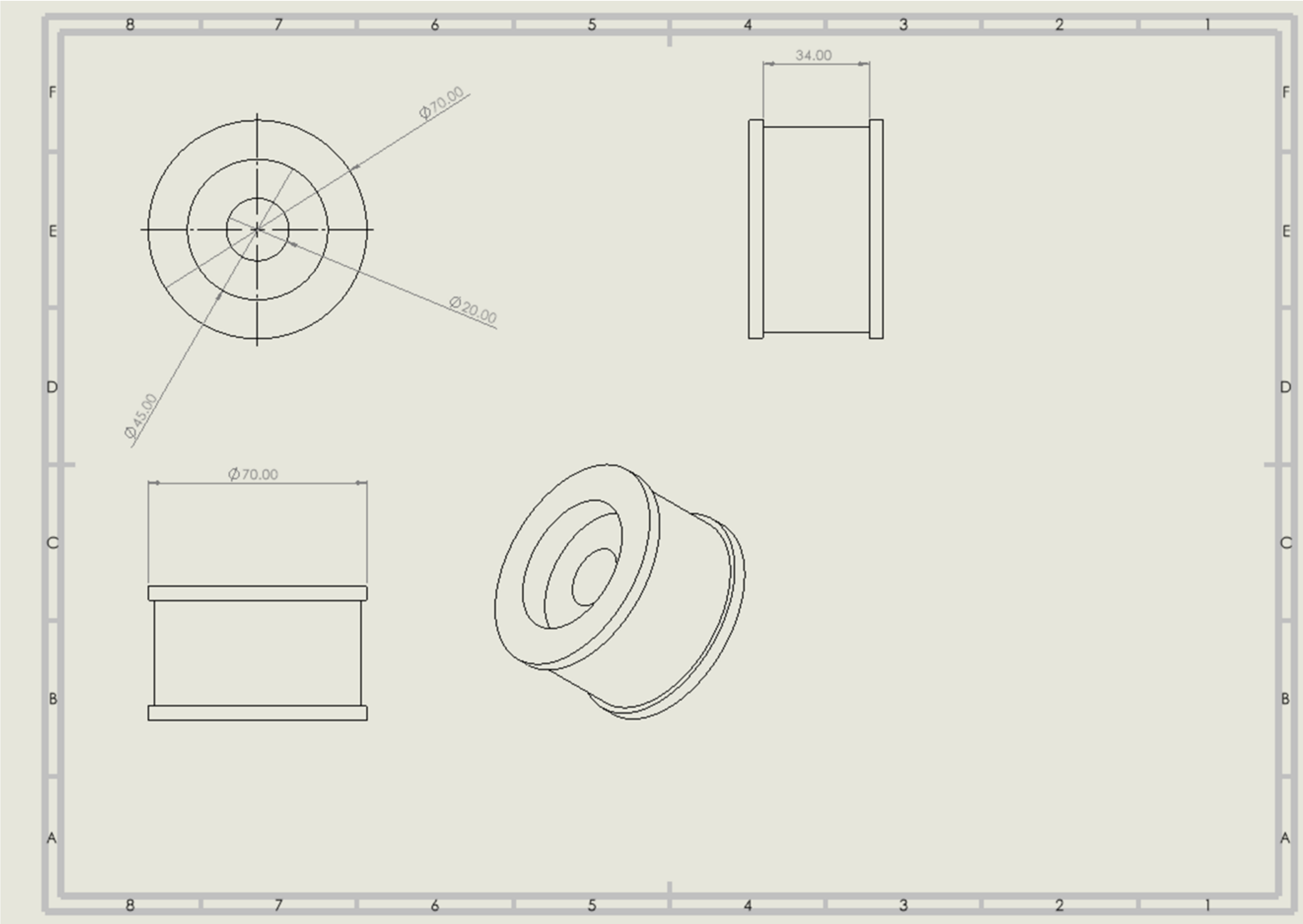
510.00



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APPENDIX C: STANDARDS

ISO 8373:2012: Robots and robotic devices — defines terms used in relation with robots and robotic devices operating in both industrial and non-industrial environments.

ISO 9283: This standard specifies the performance evaluation of servo drives for electric traction drives. It is often used in robotic systems to ensure the accuracy and reliability of the robot's movements.

ISO 9787:2013: Robots and robotic devices — Coordinate systems and motion nomenclatures

ISO 5593: This standard specifies the general requirements for the design and construction of gears and gearboxes. It covers the materials, dimensions, tolerances, and performance requirements of gears and gearboxes, and is relevant to the mechanical subsystem of a robotic solar cleaner that uses gears to transmit power and motion.

ISO/TS 15066: This standard specifies the safety requirements for collaborative robots, which are robots that are designed to work safely alongside humans in a shared workspace. It covers the design, construction, installation, operation, and maintenance of collaborative robots, with the aim of ensuring the safety of human workers and other people who may come into contact with the robot.

ISO/DIS 10218-2 ROBOTICS — Safety requirements for robot systems in an industrial environment — PART 2: Robot systems, robot applications and robot cells integration.

IEC 61131-3: This standard specifies the programming languages, programming systems, and user interfaces for programmable controllers. It is widely used in robotic systems to enable the control and automation of the robot's movements and functions.

IEC 62443: This standard specifies the security requirements for industrial control systems, including robotic systems. It covers the design, construction, installation, operation, and maintenance of these systems, with the aim of ensuring their security against cyber threats.

ASTM D2303-20e1: Standard Test Methods for Liquid-Contaminant, Inclined-Plane Tracking and Erosion of Insulating Materials

ISO/TR 20218-2:2017 International organization of standardization - Safety design for industrial robot systems ISO/CD 10218 International organization of standardization – safety requirements for industrial robots

ISO/ASTM 52900: Additive manufacturing – General principles -Terminology and definitions.

IEC 60909: This standard specifies the methods for the calculation of short-circuit currents in three-phase a.c. systems. It is often used in robotic systems to ensure the safety and reliability ofthe electrical subsystem, especially in cases where the robot is required to operate at high current levels.

ASTM F2792: Standard Guide for Additive Manufacturing of Polymer Products

APPENDIX D: CONSTRAINTS

Constraints	Yes	No
Cost	✓	
Time	✓	
Manufacturability	✓	
Sustainability	✓	
Safety	✓	
Environmental Factors	✓	

Appendix E: Code

```
//INCLUDES
#include <Arduino.h>
#include <Wire.h>
#include <MPU6050_light.h>

/*______________MOTOR PINS SETUP______________*/
int motor1Pin1 = 26;
int motor1Pin2 = 27;
int enable1Pin = 14;

int motor2Pin1 = 32;
int motor2Pin2 = 33;
int enable2Pin = 25;

const int freq = 30000;
const int pwmChannel1 = 0;
const int pwmChannel2 = 1;
const int resolution = 8;

unsigned long timerMotor = 0;
/*_____________________________________________*/

/*______________Ultrasonic PINS SETUP______________*/

#define echoPin 5          // CHANGE PIN NUMBER HERE IF YOU WANT TO USE A DIFFERENT PIN
#define trigPin 2          // CHANGE PIN NUMBER HERE IF YOU WANT TO USE A DIFFERENT PIN

long duration, distance;

/*_____________________________________________*/
```

```
/*______________IR PINS SETUP______________*/

int IR = 4; //GPIO4
int IR_Value; //Gets the value on the IR sensor

volatile int IRFlag = 0;

/*__________________________________________*/

/*______________MPU SETUP______________*/

MPU6050 mpu(Wire);
unsigned long timer = 0;
int XY_Plane_init;
int XY_Angle;

/*__________________________________________*/

/*______________Gyroscope FUNCTIONS______________*/
void gyroSetUp()
{
  byte status = mpu.begin();
  Serial.print(F("MPU6050 status: "));
  Serial.println(status);
  while(status!=0){ } // stop everything if could not connect to MPU6050

  Serial.println(F("Calculating offsets, do not move MPU6050"));
  delay(2000);
   // mpu.upsideDownMounting = true; // uncomment this line if the MPU6050 is mounted upside-down
  mpu.calcOffsets(); // gyro and accelero  // IMPORTANT(IF it doesn't work try putting (true, true) as parameters)
  Serial.println("Done!\n");
```

```
}

void PrintAngles()
{
  Serial.print("X : ");
  Serial.print(mpu.getAngleX());
  Serial.print("\tY : ");
  Serial.print(mpu.getAngleY());
  Serial.print("\tZ : "); // yaw tilt angle in the xy-plane
  Serial.println(mpu.getAngleZ());

}

/*___________________________________________________*/

/*________________UltraSonic FUNCTIONS________________*/
void US_SETUP(){
  pinMode(trigPin, OUTPUT);
  pinMode(echoPin, INPUT);
}

void Ultrasonic()
{
  digitalWrite(trigPin, LOW);
  delayMicroseconds(2);
  digitalWrite(trigPin, HIGH);
  delayMicroseconds(10);
  digitalWrite(trigPin, LOW);

  duration = pulseIn(echoPin, HIGH);
  distance = duration / 58.2;
  String disp = String(distance);

  Serial.print("Distance: ");
```

```
  Serial.print(disp);
  Serial.println(" cm");
}

/*_____________________________________________*/

/*_____________MOTOR FUNCTIONS_____________*/
void motorSetup(){

  pinMode(motor1Pin1, OUTPUT);
  pinMode(motor1Pin2, OUTPUT);
  pinMode(enable1Pin, OUTPUT);

  pinMode(motor2Pin1, OUTPUT);
  pinMode(motor2Pin2, OUTPUT);
  pinMode(enable2Pin, OUTPUT);

  ledcSetup(pwmChannel1, freq, resolution);
  ledcAttachPin(enable1Pin, pwmChannel1);
  //ledcWrite(pwmChannel1, 255);

  ledcSetup(pwmChannel2, freq, resolution);
  ledcAttachPin(enable2Pin, pwmChannel2);
  //ledcWrite(pwmChannel2, 255);

  Stop();
}

void Backward()
{
  if(!IRFlag)
  {
  digitalWrite(motor1Pin1, HIGH);
  digitalWrite(motor1Pin2, LOW);
```

```
  ledcWrite(pwmChannel1, 255);

  digitalWrite(motor2Pin1, HIGH);
  digitalWrite(motor2Pin2, LOW);

  ledcWrite(pwmChannel2, 255);
  }
  else
  {
    Stop_inf();
  }
}

void Forward()
{
  if(!IRFlag)
  {
  digitalWrite(motor1Pin1, LOW);
  digitalWrite(motor1Pin2, HIGH);

  ledcWrite(pwmChannel1, 255);

  digitalWrite(motor2Pin1, LOW);
  digitalWrite(motor2Pin2, HIGH);

  ledcWrite(pwmChannel2, 255);
  }
  else
  {
    Stop_inf();
  }
}
```

```
void Left()
{
 if(!IRFlag)
 {
 digitalWrite(motor1Pin1, HIGH);
 digitalWrite(motor1Pin2, LOW);

 ledcWrite(pwmChannel1, 255);

 digitalWrite(motor2Pin1, LOW);
 digitalWrite(motor2Pin2, HIGH);

 ledcWrite(pwmChannel2, 255);
 }
 else
 {
   Stop_inf();
 }
}

void Right()
{
 if(!IRFlag)
 {
 digitalWrite(motor1Pin1, LOW);
 digitalWrite(motor1Pin2, HIGH);

 ledcWrite(pwmChannel1, 255);

 digitalWrite(motor2Pin1, HIGH);
 digitalWrite(motor2Pin2, LOW);

 ledcWrite(pwmChannel2, 255);
 }
```

```
  else
  {
    Stop_inf();
  }

}

void Stop_inf()
{
  digitalWrite(motor1Pin1, HIGH);
  digitalWrite(motor1Pin2, LOW);

  ledcWrite(pwmChannel1, 0);

  digitalWrite(motor2Pin1, HIGH);
  digitalWrite(motor2Pin2, LOW);

  ledcWrite(pwmChannel2, 0);

  Serial.println("Solar Cleaner Job Finished (HALT)!");
  while(1){}
}

void Stop()
{
  if(!IRFlag)
  {
  digitalWrite(motor1Pin1, HIGH);
  digitalWrite(motor1Pin2, LOW);

  ledcWrite(pwmChannel1, 0);

  digitalWrite(motor2Pin1, HIGH);
  digitalWrite(motor2Pin2, LOW);
```

```
  ledcWrite(pwmChannel2, 0);
  }
  else
  {
    Stop_inf();
  }

}
/*______________________________________________*/

/*______________IR FUNCTIONS______________*/
/*

void IR_Read(){

  IR_Value = digitalRead(IR);

  if(IR_Value == 1) //Object Detected (White)
  {
    Serial.println("IR: HIGH");
  }
  else if(IR_Value == 0) //Object Not Detected (Black)
  {
    Serial.println("IR: LOW");
  }

}

portMUX_TYPE synch = portMUX_INITIALIZER_UNLOCKED;

void IRAM_ATTR ISR_IR()
{
  portENTER_CRITICAL(&synch);
```

```
  IRFlag = 1;

  portEXIT_CRITICAL(&synch);

}

*/

/*______________________________________________*/

void setup() {

  Serial.begin (115200); //Begin Serial

  //Setup MPU6050
  Wire.begin();
  gyroSetUp();



  //IR pin Setup
  pinMode(IR, INPUT_PULLUP);

  //attachInterrupt(digitalPinToInterrupt(IR), ISR_IR, FALLING);



  //Ultrasonic Init
  US_SETUP();

  //Motor Init
  motorSetup();
```

```
  mpu.update();

  XY_Plane_init = mpu.getAngleZ();

}

void loop() {
  mpu.update();

  Ultrasonic();

  //Serial.println("From outside ultrasonic");

  if(distance < 20 ) //20 cm
  {
    //Serial.println("Entered First function distance < 20.. move Forward");
    Forward();

    IRFlag = digitalRead(IR);

    if(IRFlag)
    {
      Serial.println("Entered Stop_inf from first function");
      Stop_inf();
    }

  }
  else if(distance >20)
  {
    Serial.println("Entered Second function distance > 20 .. Stopping for 1 sec");
    Stop();
    delay(1000);

    Serial.println("Second function going backward 1");
```

```
Backward();

while(1)
{
 Ultrasonic();
 Serial.println("From Ultrasonic: 1 inside second function");
 if(distance < 20)
 {
  Stop();
  break;
 }
 delay(200);
}

mpu.update();

XY_Angle = mpu.getAngleZ();
Serial.println("Deciding to go Left or Right");
Serial.print("XY_Angle = "); Serial.println(XY_Angle);

if((XY_Angle > -45)) // go Right
{
 Serial.println("Going Right... XY_Angle > -45");

 Right();

 Serial.println("Trying to Reach angle -90 [RIGHT]");

 Right90();

 Serial.println("Going FURTHUR [RIGHT to -180]!!!");

 Right();
```

```
    Serial.println("Trying to Reach angle -180 [RIGHT]");

    Right180();

   }
   else if((mpu.getAngleZ() < -135)) // go Left
   {

    Serial.println("Going Left... XY_Angle > -135");

    Left();

    Serial.println("Trying to Reach angle -90 from -180 [LEFT]");

    Left90();

    Serial.println("Going FURTHUR [LEFT to 0]!!!");

    Left();

    Serial.println("Trying to Reach angle 0 [LEFT]");

    Left0();

   }

  }
  delay(200);

 }

 //----------------------------------------------------------------------------------------------------
-----------------
```

```
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void Right90() {
  while (1)  //From 0 to -90 degree
  {

    mpu.update();
```

```
    if ((millis() - timer) > 10) {  // print data every 10ms

     XY_Angle = mpu.getAngleZ();
     Serial.print("Reaching -90... XY_Angle = ");
     Serial.println(XY_Angle + XY_Plane_init);

       if  ((XY_Angle  >  (-92  +  XY_Plane_init))  &&  (XY_Angle  <  (-88  +
XY_Plane_init))) {

      Serial.println("Angle -90 [REACHED!]... Stopping for 1 sec");
      Stop();
      delay(1000);
      Serial.println("Angle -90 [REACHED!]... Now Moving Forward for 3.5 sec");
      Forward();

      timerMotor = millis();

      while (1) {
       Ultrasonic();

       if ((distance > 20) || (millis() - timerMotor) > 3500)  //if distance < 20 cm or if
3.5sec has passed
       {
        Serial.println("Angle -90 [REACHED!]... After Forward.. NOW STOP!");
        Stop();
        delay(1000);

        if (distance > 20) {
         Serial.println("Angle -90 [REACHED!]... Distance > 20 Going backward");
         Backward();

         while (1) {
          Ultrasonic();
```

```
          if (distance < 20) {
            Serial.println("Angle -90 [REACHED!]... Distance < 20 Stopping");
            Stop();
            break;
          }
          delay(200);
        }
      }

      break;
    }

    delay(200);
  }

  break;
 }

 timer = millis();
}

if (IRFlag) {
 Serial.println("In Reaching [RIGHT!] -90 function.. [Stop_inf] Called!!! ");
 Stop_inf();
}
}
}

void Right180() {

 while (1)  //From -90 to -180 degree
 {

  mpu.update();
```

```
if ((millis() - timer) > 10) {  // print data every 10ms

  XY_Angle = mpu.getAngleZ();
  Serial.print("Reaching -180... XY_Angle = ");
  Serial.println(XY_Angle + XY_Plane_init);

     if ((XY_Angle > (-182 + XY_Plane_init)) && (XY_Angle < (-178 +
XY_Plane_init))) {

    Serial.println("Angle -180 [REACHED!]... Stopping for 1 sec");

    Stop();

    Serial.println("Angle -180 [REACHED!]... Now Moving Forward for 2 sec");
    delay(1000);

    /*
    Forward();
    timerMotor = millis();

    while (1) {
      Ultrasonic();

      if ((distance > 20) || (millis() - timerMotor) > 2000)  //if distance < 20 cm or if
1sec has passed
      {

        Serial.println("Angle -180 [REACHED!]... After Forward.. NOW STOP!");

        Stop();
        delay(1000);

        if (distance > 20) {
```

```
          Serial.println("Angle -180 [REACHED!]... Distance > 20 Going backward");

          Backward();

          while (1) {
            Ultrasonic();
            if (distance < 20) {
              Serial.println("Angle -180 [REACHED!]... Distance < 20 Stopping");
              Stop();
              break;
            }
            delay(200);
          }
        }

        break;
      }

      delay(200);
    }

    */

    break;
  }

  timer = millis();
 }

 if (IRFlag) {
  Serial.println("In Reaching [RIGHT!] -180 function.. [Stop_inf] Called!!! ");
  Stop_inf();
 }
}
```

```
}

void Left90() {
  while(1) //From -180 to -90 degree
    {
     mpu.update();

     if((millis()-timer)>10)
     { // print data every 10ms

       XY_Angle = mpu.getAngleZ();
                   Serial.print("Reaching   -90   [Going   Left]...   XY_Angle   =   ");
Serial.println(XY_Angle + XY_Plane_init);

            if(  (XY_Angle  >  (-92  +  XY_Plane_init))   &&   (XY_Angle  <  (-88  +
XY_Plane_init))  )
       {
        Serial.println("Angle -90 [REACHED!] [Going Left]... Stopping for 1 sec");
        Stop();
        delay(1000);
         Serial.println("Angle -90 [REACHED!] [Going Left]... Now Moving Forward
for 3.5 sec");

        Forward();
        timerMotor = millis();

        while(1)
        {
          Ultrasonic();

          if((distance > 20) || (millis() - timerMotor) > 3500) //if distance < 20 cm or if
3.5 sec has passed
          {
```

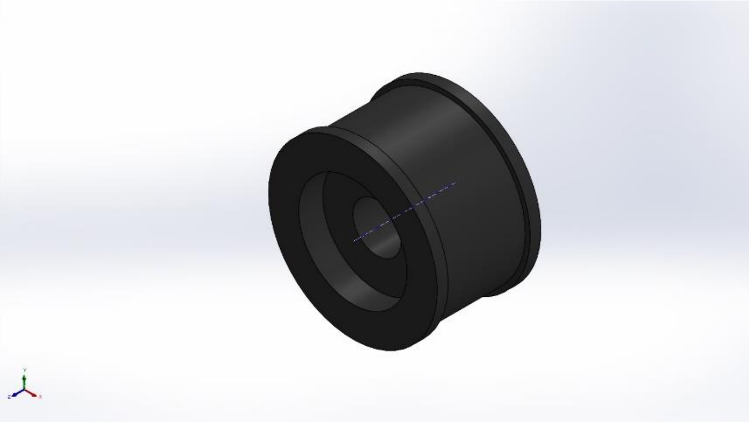
```
        Serial.println("Angle -90 [REACHED!] [Going Left]... After Forward.. NOW STOP!");
        Stop();
        delay(1000);

        if(distance > 20)
        {
         Serial.println("Angle -90 [REACHED!] [Going Left]... Distance > 20 Going backward");
         Backward();

         while(1)
         {
          Ultrasonic();
          if(distance < 20)
          {
           Serial.println("Angle -90 [REACHED!]... Distance < 20 Stopping");
           Stop();
           break;
          }
          delay(200);
         }
        }

        break;
       }

      delay(200);
     }

     break;

    }
```

```
            timer = millis();

          }

          if(IRFlag)
          {
            Serial.println("In Reaching [LEFT!] -90 function.. [Stop_inf] Called!!! ");
            Stop_inf();
          }

        }
    }

    void Left0()
    {
      while(1) //From -90 to 0 degree
        {
          mpu.update();

          if((millis()-timer)>10)
          { // print data every 10ms

            XY_Angle = mpu.getAngleZ();
                          Serial.print("Reaching 0 [Going Left]... XY_Angle = ");
Serial.println(XY_Angle + XY_Plane_init);

                 if( (XY_Angle > (-2 + XY_Plane_init)) && (XY_Angle < (2 +
XY_Plane_init)) )
            {

              Serial.println("Angle 0 [REACHED!]... Stopping for 1 sec");

              Stop();
```

```
delay(1000);

/*
Serial.println("Angle 0 [REACHED!]... Now Moving Forward for 2 sec");



Forward();
timerMotor = millis();

while(1)
{
  Ultrasonic();

   if((distance > 20) || (millis() - timerMotor) > 2000) //if distance < 20 cm or if
1sec has passed
  {
    Serial.println("Angle 0 [REACHED!]... After Forward.. NOW STOP!");
    Stop();
    delay(1000);

    if(distance > 20)
    {
      Serial.println("Angle 0 [REACHED!]... Distance > 20 Going backward");
      Backward();

      while(1)
      {
        Ultrasonic();
        if(distance < 20)
        {
          Serial.println("Angle 0 [REACHED!]... Distance < 20 Stopping");
          Stop();
          break;
        }
```

```
                delay(200);
               }
             }

             break;
           }

           delay(200);
         }

         */

         break;

        }
        timer = millis();

      }

      if(IRFlag)
      {
          Serial.println("In Reaching [LEFT!] -90 to 0 Degree function.. [Stop_inf]
Called!!! ");
        Stop_inf();
      }

     }
  }
```

APPENDIX F: Structural Analysis



Simulation of Back Wheel

Date: Wednesday, June 19, 2024
Designer: Hesham
Study name: Static 5
Analysis type: Static

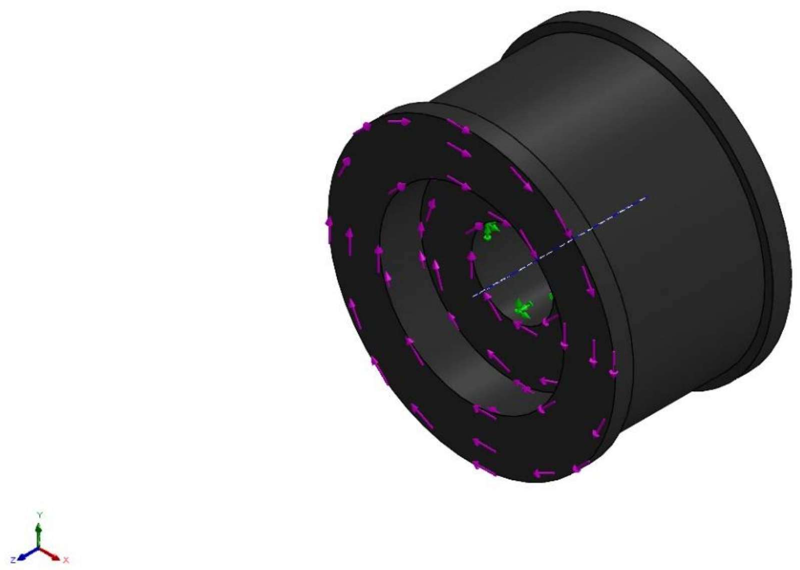
Table of Contents

Description

No Data

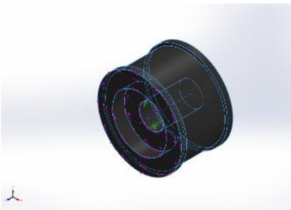
Assumptions

Model Information



Model name: Back Wheel

Current Configuration: Default

Solid Bodies			
Document Name and Reference	Treated As	Volumetric Properties	Document Path/Date Modified
Cut-Extrude6 	Solid Body	Mass:0.143388 kg Volume:0.000124685 m^3 Density:1,150 kg/m^3 Weight:1.4052 N	D:\Graduation Book\Back Wheel.SLDPRT Jun 19 14:40:29 2024

Study Properties

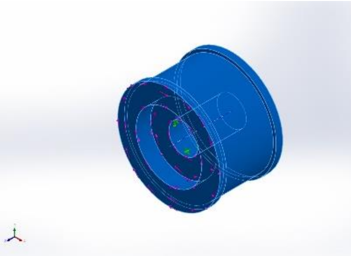
Study name	Static 5

Analysis type	Static
Mesh type	Solid Mesh
Thermal Effect:	On
Thermal option	Include temperature loads
Zero strain temperature	298 Kelvin
Include fluid pressure effects from SOLIDWORKS Flow Simulation	Off
Solver type	Automatic
Inplane Effect:	Off
Soft Spring:	Off
Inertial Relief:	Off
Incompatible bonding options	Automatic
Large displacement	Off
Compute free body forces	On
Friction	Off
Use Adaptive Method:	Off
Result folder	SOLIDWORKS document (D:\Graduation Book)

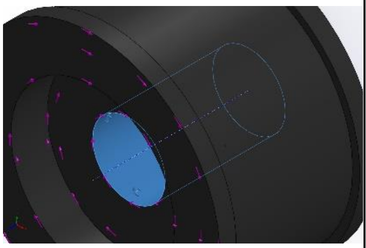
Units

Unit system:	SI (MKS)
Length/Displacement	mm
Temperature	Kelvin
Angular velocity	Rad/sec
Pressure/Stress	N/m^2

Material Properties

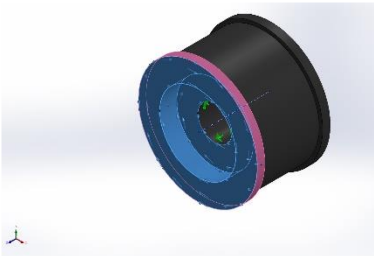
Model Reference	Properties	Components
	Name: **Nylon 101** Model type: **Linear Elastic Isotropic** Default failure criterion: **Max von Mises Stress** Yield strength: **6e+07 N/m^2** Tensile strength: **7.92897e+07 N/m^2** Elastic modulus: **1e+09 N/m^2** Poisson's ratio: **0.3** Mass density: **1,150 kg/m^3** Thermal expansion coefficient: **1e-06 /Kelvin**	**SolidBody1(Cut-Extrude6)(Back Wheel)**
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** **1 face(s)** **Type:** **Fixed Geometry**

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	**-0.000893414**	**-0.0024085**	**2.98023e-08**	**0.00256887**
Reaction Moment(N.m)	**0**	**0**	**0**	**0**

Load name	Load Image	Load Details
Torque-1		**Entities:** **3 face(s)** **Reference:** **Face< 1 >** **Type:** **Apply torque** **Value:** **1 N.m**

Connector Definitions

No Data

Interaction Information

No Data

Mesh information

Mesh type	Solid Mesh
Mesher Used:	Blended curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	4.9973 mm

Minimum element size	4.9973 mm
Mesh Quality	High

Mesh information - Details

Total Nodes	15015
Total Elements	9705
Maximum Aspect Ratio	3.4053
% of elements with Aspect Ratio < 3	99.6
Percentage of elements with Aspect Ratio > 10	0
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:02
Computer name:	

Sensor Details

No Data

Resultant Forces

Reaction forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N	-0.000893414	-0.0024085	2.98023e-08	0.00256887

Reaction Moments

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	0

Free body forces

Selection set	Units	Sum X	Sum Y	Sum Z	Resultant

Entire Model	N	9.89437e-06	-9.35793e-06	-1.86265e-09	1.36187e-05

Free body moments

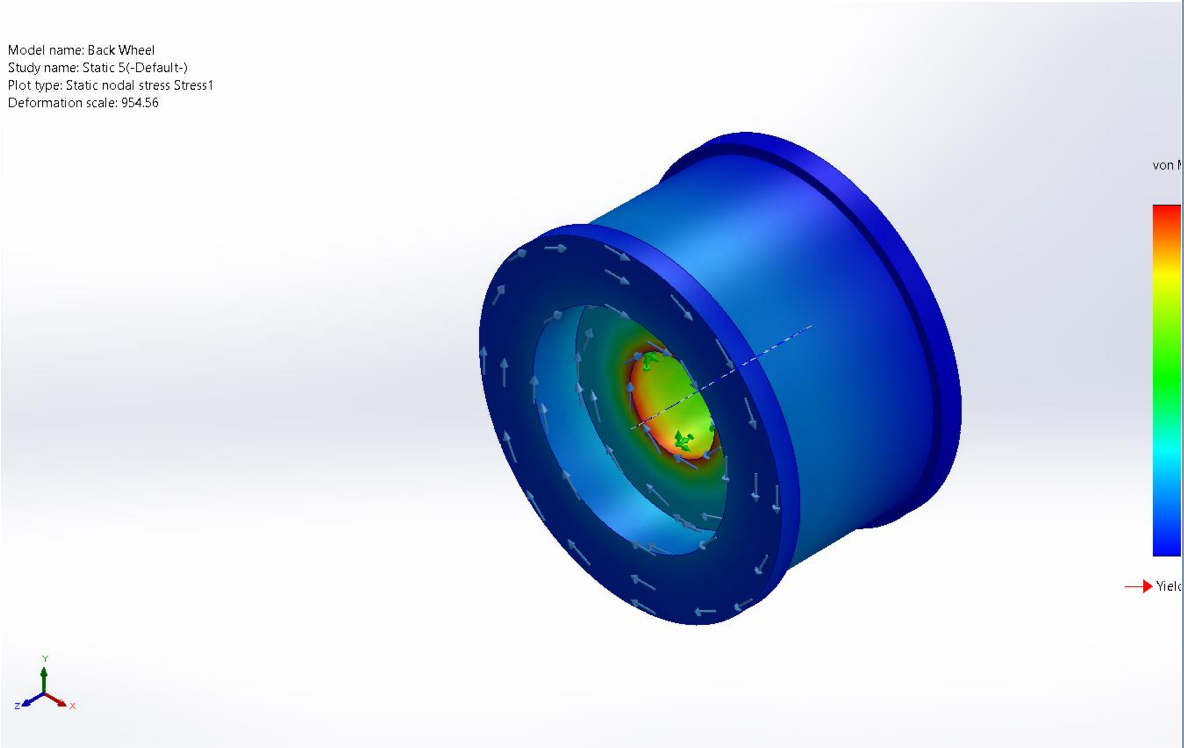
Selection set	Units	Sum X	Sum Y	Sum Z	Resultant
Entire Model	N.m	0	0	0	1e-33

Beams

No Data

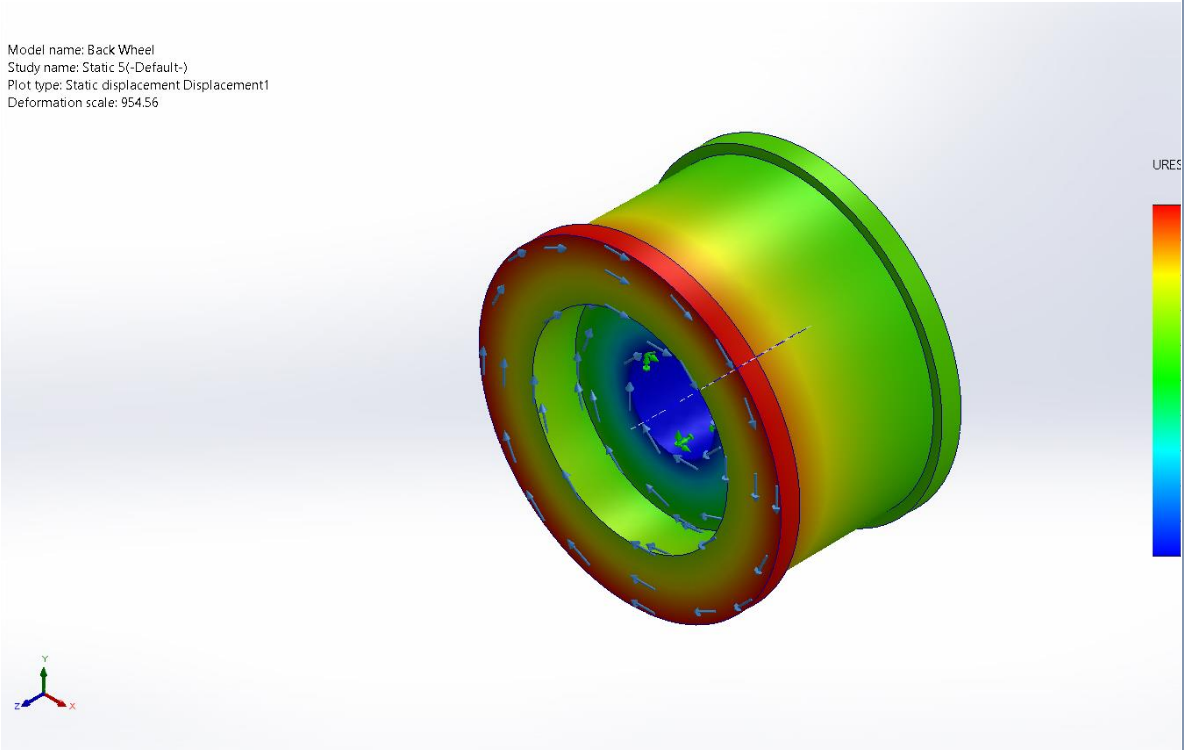
Study Results

Name	Type	Min	Max
Stress1	VON: von Mises Stress	1.654e+02N/m^2 Node: 14817	4.066e+05N/m^2 Node: 835



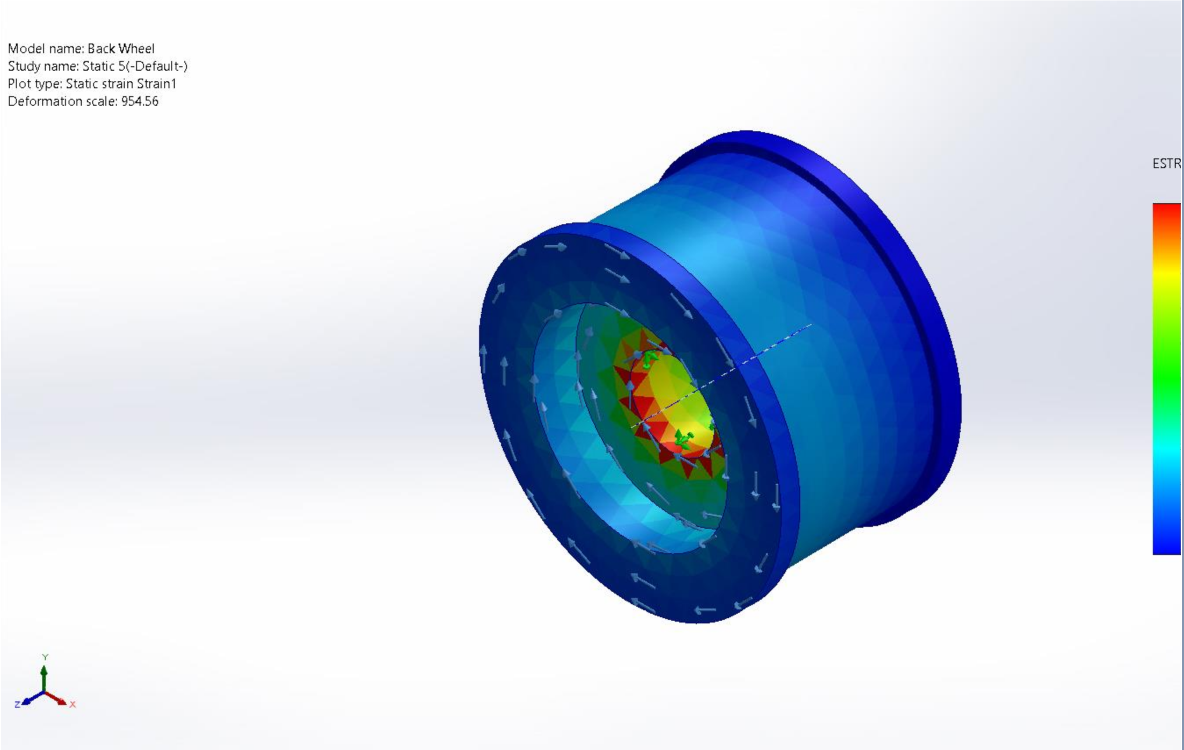
Back Wheel-Static 5-Stress-Stress1

Name	Type	Min	Max
Displacement1	URES: Resultant Displacement	0.000e+00mm Node: 11	7.337e-03mm Node: 184



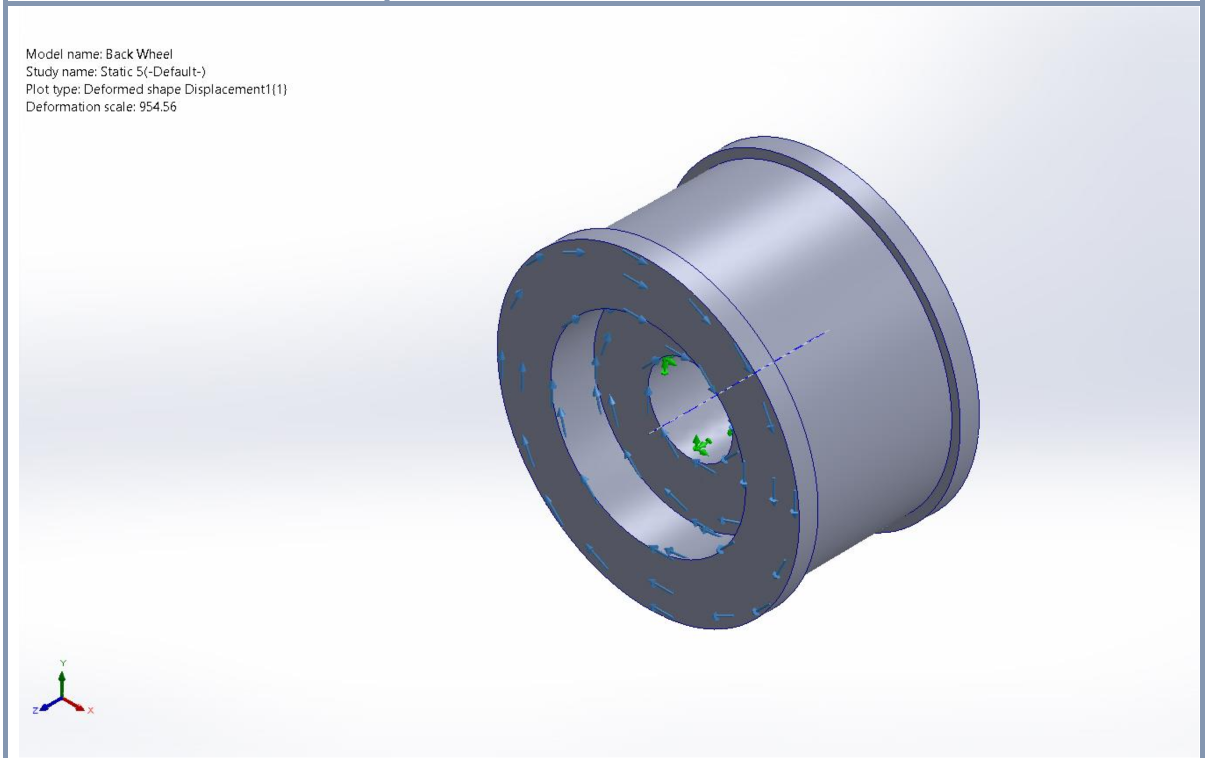
Back Wheel-Static 5-Displacement-Displacement1

Name	Type	Min	Max
Strain1	ESTRN: Equivalent Strain	1.295e-06 Element: 1564	2.731e-04 Element: 2434



Back Wheel-Static 5-Strain-Strain1

Name	Type
Displacement1{1}	Deformed shape



Back Wheel-Static 5-Displacement-Displacement1{1}

الملخص

ترتبط الطاقة أو الكفاءة التي تنتجها الوحدات الكهروضوئية الشمسية بإشعاع الشمس المتوفر والمحتوى الطيفي، بالإضافة إلى عوامل أخرى مثل الأداء البيئي والمناخي وأداء المكونات والنظام المتأصل.

يتعلق مشروعنا بتصميم وتطوير نظام تنظيف الألواح الشمسية. الهدف الرئيسي من ذلك هو تعزيز إنتاج الطاقة الشمسية الذي سيكون مستقلاً ومراقبًا عن بعد (SPAC) الكهروضوئية من خلال تصميم وتصنيع نظام التنظيف الآلي.

إذا تم تنفيذ المهمة يدويًا، فستكون مكلفة للغاية وتستغرق وقتًا طويلاً. ومن أجل ضمان جودة التنظيف، سيتم استخدام رشاشات المياه ومواد المسح الخاصة في الهيكل المصمم للآلية.

المقترح على جزء من نظامنا الكهروضوئي فوق مبنى الهندسة الميكانيكية بجامعة الزقازيق. SPAC سيتم اختبار نظام سيتم تقييم أداء النظام الكهروضوئي ومقارنته بالأداء الأساسي لقياس التحسن.