



International Journal of Innovative Research in Science Engineering and Technology (IJIRSET)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



Impact Factor: 8.699

Volume 14, Issue 5, May 2025

Design and Development of Semi-Automatic Solar Panel Cleaning Robot Integrated with IOT

Shibi D, Tinif Faustine J, Vignesh A, Dhanus Kumar G

Dept. of Mechanical Engineering, Sri Shakthi Institute of Engineering and Technology, Coimbatore, India

M.Karthick

Assistant Professor, Dept. of Mechanical Engineering, Sri Shakthi Institute of Engineering and Technology,
Coimbatore, India

ABSTRACT: The buildup of dust, dirt, and various airborne particles on solar photovoltaic (PV) panels presents a significant obstacle to achieving optimal energy production, particularly in arid and semi-arid areas characterized by conditions such as sandstorms, elevated aerosol levels, and limited rainfall. To tackle this issue, this project introduces the design and development of a semi-automated, Internet of Things (IoT)-enabled cleaning robot for solar panels. The proposed solution includes a compact and cost-efficient robotic platform that can be controlled via an IoT-based joystick interface, enabling users to operate the robot remotely from any location with internet access. The robot is powered by an ESP32 microcontroller, which supports both control and connectivity, and is equipped with a real-time clock (RTC) module to facilitate scheduled cleaning cycles according to user preferences or environmental conditions. The mechanical cleaning system employs a soft, flexible brush specifically designed to gently dislodge and eliminate stubborn dirt particles without damaging the panel's surface. Additionally, the system is water-efficient, requiring minimal to no water during the cleaning process, making it especially appropriate for use in arid regions where water resources are limited.

KEYWORDS: Solar Panels, Dust Accumulation, Automated Cleaning, Efficiency Improvement, Sustainability

I. INTRODUCTION

Solar energy has become a leading renewable energy source due to its abundance, reliability, and environmental benefits. Solar photovoltaic (PV) panels play a crucial role in converting sunlight into electricity, significantly contributing to the reduction of carbon emissions. However, a major challenge for solar PV systems is the accumulation of dust and dirt on their surfaces, which reduces their ability to capture sunlight effectively. This issue is particularly pronounced in arid and semi-arid regions, where high levels of airborne particles, frequent sandstorms, and scarce rainfall worsen the problem. Studies indicate that dust buildup can lead to power losses ranging from 25% to 40%, depending on the duration and severity of exposure.

Traditional methods for cleaning solar panels, such as manual cleaning, are often labor-intensive, time-consuming, and require significant amounts of water—a scarce resource in drought-prone areas. Additionally, manual cleaning can result in inconsistent cleaning schedules and variable effectiveness, further exacerbating energy losses. To address these limitations, there is a pressing need for an automated and water-efficient solution to maintain the optimal performance of solar PV systems.

The project, “Design and Fabrication of Fully Autonomous Solar Panel Cleaning Robot,” seeks to address this issue by developing a self-operating, waterless cleaning system tailored for small-scale solar panels. This robotic solution incorporates advanced technologies, including the ESP32 micro-controller and a real-time clock, to automate cleaning schedules based on environmental conditions. The system features a dual-stage cleaning mechanism: a high-velocity air blower to remove loose dust particles, followed by a flexible, non-abrasive brush to clear stubborn dirt without damaging the panels. This innovative approach minimizes water usage, eliminates manual intervention, and provides a sustainable and efficient solution for enhancing solar panel performance.

1.1 Pv System

Solar energy production harnesses sunlight to generate electricity, making it one of the most sustainable and eco-friendly energy sources. By using photovoltaic (PV) panels or concentrated solar power systems, solar energy can be converted into usable power for homes, industries, and businesses. Its abundance and renew-ability make it a vital solution for reducing dependence on fossil fuels and combating climate change. Solar power has seen rapid growth due to advancements in technology, falling costs, and increasing global demand for clean energy .As an essential component of the renewable energy mix, solar production plays a critical role in creating a sustainable future.

1.2Pv Uses

Photovoltaic (PV) technology is commonly used to produce clean electricity across multiple fields. In homes, rooftop PV systems help lower electricity costs and reduce reliance on the power grid. Businesses and industries use PV setups to run their operations more sustainably. Utility-scale solar farms contribute renewable energy to the grid, while standalone PV units bring power to isolated locations. Portable solar gadgets like lights and chargers offer mobile energy solutions. In agriculture, PV is used for running irrigation systems and managing greenhouses, and in public services, it powers things like traffic lights and streetlamps. PV also plays a vital role in space exploration by supplying energy to satellites and missions beyond Earth.

1.3 Panel Cleaning

Solar panels are built to absorb sunlight effectively, but their efficiency can drop noticeably when dust, dirt, bird droppings, or other debris collect on the surface. Keeping the panels clean is crucial for maintaining peak performance and extending their service life. Regular cleaning helps ensure maximum sunlight absorption, resulting in better energy generation.

Typically, cleaning involves the use of gentle brushes or sponges, water, and mild, non-abrasive cleaners to prevent surface damage. It's recommended to clean panels during the early morning or late evening when they are cool, to avoid thermal shock or rapid water evaporation. For larger solar installations, automated cleaning systems and self-cleaning technologies are becoming more common to improve convenience and effectiveness.

Timely and proper maintenance can enhance solar panel output by anywhere from 5% to 20%, depending on how dirty they are. Therefore, maintaining a regular cleaning routine is essential for achieving maximum energy efficiency and long-term performance.

1.4 Manual Cleaning

Manual cleaning of solar panels is a straightforward and cost-effective method to maintain their efficiency and performance. It involves physically removing dirt, dust, bird droppings, and other debris that accumulate on the panel surface, which can hinder sunlight absorption and reduce energy output.

This process typically requires basic cleaning tools such as soft brushes, sponges, microfiber cloths, water, and mild, non-abrasive detergents. Care must be taken to avoid using harsh chemicals or abrasive materials that could damage the panels. Cleaning is best performed during early mornings or evenings when the panels are cooler to prevent thermal stress and ensure safety.

Though labor-intensive, manual cleaning is particularly suited for small to medium-scale installations and offers precise control, ensuring thorough removal of stubborn grime and maintaining optimal energy production.

1.5 Automated Cleaning

Automated cleaning systems offer a highly efficient, low-maintenance way to keep photovoltaic (PV) panels clean and functioning at optimal levels. These systems eliminate the need for manual labor by automatically removing dust, dirt, and other debris, which helps maintain consistent energy production.

Common types of automated cleaners include robotic devices, dry brush systems, and spray mechanisms, often operating on pre-set schedules. Some advanced models are equipped with sensors that detect dirt buildup and trigger cleaning only when necessary. These technologies are especially valuable in large solar farms or in isolated and dry regions where manual cleaning is difficult or expensive.

By minimizing the need for labor, reducing water use, and limiting system downtime, automated cleaning solutions improve the long-term efficiency, dependability, and cost performance of solar power systems.

1.6 Objective

- Maintain maximum solar panel efficiency by removing dust, dirt, and debris that obstruct sunlight.
- Operate without human intervention using iot, enabling navigation and cleaning tasks.
- Function reliably in remote, large-scale, or difficult terrains where manual cleaning is impractical or costly.
- Use an onboard camera to inspect solar panels for physical damage or cracks or dirt removal during operation.
- Improve the overall reliability, lifespan, and energy output of solar energy systems.
- Lower labor and maintenance expenses associated with traditional manual cleaning methods.

1.7 Scope

The project focuses on designing and developing a fully autonomous solar panel cleaning robot aimed at maximizing the efficiency and energy output of photovoltaic systems. The robot will be equipped with advanced sensors, navigation systems, and cleaning mechanisms to detect and remove dirt, dust, and debris effectively.

Its scope includes ensuring compatibility with various solar panel sizes and installations, including inclined, horizontal, and vertical arrays. The system will be designed for minimal water usage, energy efficiency, and adaptability to harsh environmental conditions, such as arid or remote locations.

The project addresses the need for a cost-effective, low-maintenance, and scalable solution for solar panel cleaning, targeting large-scale solar farms, industrial setups, and residential installations to improve overall sustainability and performance.

II. LITERATURE REVIEW

2.1 Design And Implementation Of A Waterless Solar Panel Cleaning System

Dust buildup on solar photovoltaic (PV) panels is a major factor contributing to reduced energy output. Research by Suleiman et al. (2014) revealed that dust accumulation can lower the amount of sunlight reaching solar cells, causing energy losses between 20% and 50% in dry and dusty regions. This problem is especially severe in areas like the Middle East and North Africa, where high dust levels and frequent sandstorms make panel maintenance a significant challenge. Additionally, Sayigh et al. (1985) found that the type of dust and how firmly it adheres to panel surfaces significantly affects the effectiveness of cleaning methods.

Traditional manual cleaning methods, while commonly used, are labor-intensive, time-consuming, and require substantial amounts of water—a major concern in arid regions where water is both scarce and costly. Manual cleaning can also lead to inconsistent results due to uneven cleaning patterns and irregular schedules. These challenges underline the importance of developing automated cleaning technologies that ensure reliable, uniform, and resource-efficient maintenance of solar panels.

2.2 Dust Impact On Solar Pv Performance Review Of Optimal Claning Technique For Yield Enhancement Across Various Environmental Conditions

Advancements in robotics and automation have led to the development of cleaning robots for solar PV systems. Luo et al. (2015) investigated an automated robotic cleaning mechanism equipped with rotating brushes and found it to be effective in removing dust. However, their study identified challenges related to wear and tear of the brushes and potential surface damage caused by abrasive cleaning components. Additionally, they noted that many automated systems are not cost-effective for small-scale solar panels, where the cleaning costs might outweigh the financial benefits of increased energy output. This highlights the need for a robust, non-abrasive, and affordable solution tailored for small installations.

However, the study revealed that air-based systems alone often fail to remove sticky dirt and other contaminants that adhere strongly to the panel surfaces. To address this, a dual-stage cleaning mechanism—combining air blowers with brushes—has been proposed as an effective solution. This dual-stage approach ensures comprehensive cleaning by targeting both loose and stubborn particles, minimizing power losses caused by incomplete cleaning.

2.3 Automated, Robotic Dry-Cleaning Of Solar Panel In Thuwal, Saudi Arabia Using A Silicone Rubber Brush

Automation has been a critical focus area for solar panel cleaning systems. Khan et al. (2018) developed an Arduino-based cleaning robot that followed per-programmed schedules to clean solar panels periodically. While their system showed significant improvements in energy output, it lacked adaptability to changing environmental conditions, such as unexpected dust storms or extended periods of low rainfall. The incorporation of more advanced micro-controllers, such as the ESP 32, addresses this limitation by enabling real-time decision-making and dynamic cleaning schedules. The ESP 32 micro-controller, equipped with wireless connectivity and a real-time clock, allows the system to monitor environmental parameters and optimize cleaning intervals, enhancing overall efficiency and adaptability.

The study highlighted that non-abrasive materials are essential to ensure long-term panel durability, particularly for systems that undergo frequent cleaning. The use of flexible, non-abrasive brushes in this project aligns with these findings, ensuring effective cleaning while protecting the integrity of the panels.

2.4 Autonomous Robot For Cleaning Photovoltaic Panel In Desert Zone

The economic benefits of automated cleaning systems are significant, particularly in high-dust regions. Mehmood et al. (2019) conducted experiments on an automated cleaning system and reported a power output increase of 25–35% following cleaning in areas with heavy dust deposition. Their findings demonstrated that even a small increase in efficiency could translate into substantial financial gains over the lifespan of a solar PV system. Automated systems not only reduce downtime associated with manual cleaning but also ensure consistent energy output, making them an economically viable solution in the long term.

They argued that systems that rely heavily on water or consume significant amounts of electricity for operation may offset the environmental benefits of solar energy. This project's waterless cleaning design, combined with the low power consumption of the ESP 32 micro-controller, ensures that it aligns with sustainable energy practices.

2.5 Design And Implementation Of A Waterless Solar Panel Cleaning System

Dust accumulation significantly reduces the efficiency of solar photovoltaic (PV) systems, with studies reporting power losses of 6–45% and efficiency drops of 13–38%. Traditional manual cleaning methods—using water, brushes, or detergents—are labor-intensive, costly, and pose safety risks, especially in arid regions where water is scarce. As a result, researchers have developed various automated cleaning systems. Habib et al. introduced a waterless Arduino-based system using an air blower and wiper, while Dahoud et al. incorporated GSM modules for real-time solar panel cleaning. Others proposed robotic systems with rainwater harvesting or IoT integration for efficiency monitoring.

While some designs employ electrostatic or surface acoustic wave cleaning, these methods often face challenges in dust detachment rates or operational complexity. The reviewed journal proposes a cost-effective, automated waterless cleaning system using an Arduino Uno, real-time clock, air blower, and rotating brush. This two-stage system removes both loose and sticky dust without water, making it ideal for dry environments. Compared to other approaches, it balances simplicity, efficiency, and sustainability, achieving a 26.23% increase in power output. These insights highlight the importance of reliable, low-maintenance, and water-free cleaning solutions for optimizing solar energy harvesting in dust-prone regions.

INTERNET OF THINGS

The Internet of Things (IoT) refers to a network of smart devices—including cars, home appliances, and other everyday objects—that are equipped with electronics, software, and sensors to communicate and share data over the internet.

While traditional internet-connected devices include computers, smartphones, and tablets, IoT expands this connectivity to regular, non-digital objects, allowing them to be monitored and controlled remotely. This means everything from smart refrigerators to automated farming equipment can now collect data, communicate with other devices, and be managed from anywhere.



Representation of IOT

The evolution of IoT has been driven by advancements in multiple technologies, such as real-time data analysis, machine learning, wireless sensor networks, and automation systems. These innovations allow IoT to integrate seamlessly into different fields, including smart homes, industrial automation, and precision agriculture, making daily tasks more efficient and improving overall productivity.

HOW IOT WORKS

The Internet of Things (IoT) ecosystem is made up of smart, web-enabled devices that can collect, share, and act on data from their surroundings. These devices are equipped with sensors, processors, and communication tools, allowing them to connect and exchange information.

IoT devices typically send the data they gather to an IoT gateway or an edge device, where it is either processed locally or sent to the cloud for further analysis. Some IoT devices can even communicate directly with each other, making decisions based on the shared data without needing human input.

While people can interact with these devices—for example, to set them up, give commands, or retrieve information—they are designed to function automatically, handling most tasks on their own. The way these devices connect and communicate depends on the specific IoT applications they are used for, whether in smart homes, healthcare, agriculture, or industrial automation.

HARDWARE REQUIREMENTS POWER SUPPLY CIRCUIT

Power supply is a reference to a source of electrical power. A device or system that supplies electrical or other types of energy to an output load or group of loads is called a power supply unit or PSU. The term is most commonly applied to electrical energy supplies, less often to mechanical ones, and rarely to others. Power supplies for electronic devices can be broadly divided into linear and switching power supplies. The linear supply is a relatively simple design that becomes increasingly bulky and heavy for high current devices; voltage regulation in a linear supply can result in low efficiency. A switched-mode supply of the same rating as a linear supply will be smaller, is usually more efficient, but will be more complex.

Esp32

The ESP 32 is a low-power system-on-chip (SoC) with integrated Wi-Fi and Bluetooth capabilities is shown in Fig 3.1. It features dual-core processing and a wide range of peripherals, making it ideal for applications that require wireless connectivity and real-time control. In your project, the ESP 32 micro-controller is used to manage the cleaning system's operations, including controlling the motors, sensors, and timing of the cleaning process. It integrates a real-time clock for optimized scheduling and can be connected to external devices for remote monitoring, which is essential for real-time decision-making in an autonomous cleaning robot.



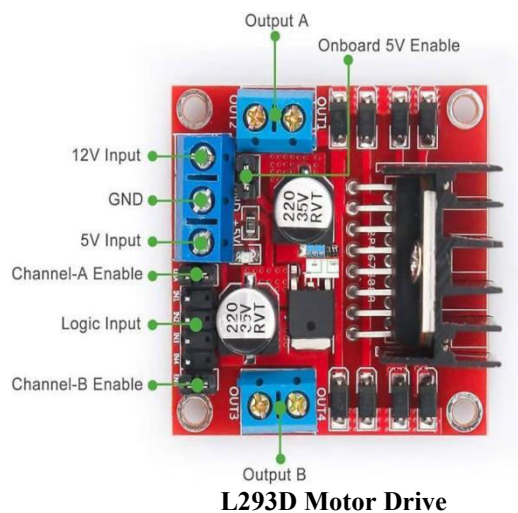
BLDC Motor

A Brush less DC Motor (BLDC) that is shown in Fig 3.2 is a type of electric motor that is powered by direct current (DC) but does not use brushes for commutation, unlike traditional DC motors. The absence of brushes reduces wear and tear, increases efficiency, and allows for smoother operation. BLDC motors are ideal for your project due to their high efficiency, reliability, and low maintenance requirements. They are used in the robotic cleaning system to drive the movement of the robot and/or the cleaning mechanism (such as rotating brushes or air blowers). Their efficiency ensures low energy consumption, critical for the autonomous nature of the robot



L293D MOTOR DRIVE

The L293D motor driver IC (integrated circuit) used to control the direction and speed of DC motors. It's commonly used in robotics, automation, and other projects where precise motor control is required.



Ultra Sonic Sensor

An ultrasonic sensor shown in Fig 3.5 is an electronic device used to measure distances by emitting ultrasonic sound waves and detecting the reflected waves. It consists of a transmitter that emits high-frequency sound waves (typically above 20 kHz) and a receiver that captures the echo when the waves bounce back from an object. The time taken for the sound to return is used to calculate the distance to the object. Ultrasonic sensors are widely used in robotics, automation, and obstacle detection systems due to their accuracy, reliability, and ability to function in various environmental conditions, including low-light or dusty areas.



III. DESIGN

3.4.1 Base Design

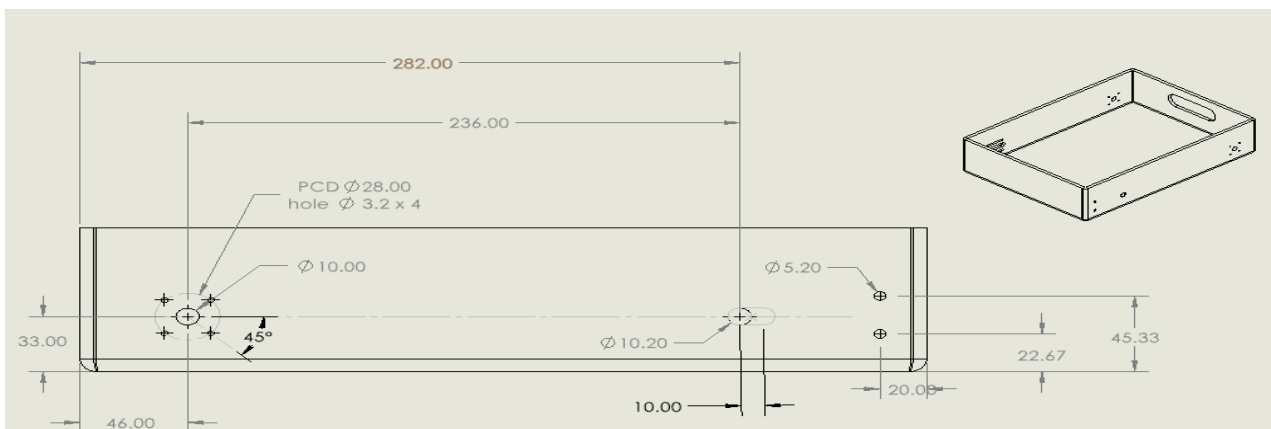


Fig 3.14 Base Drawing

This is the fabricated base of the solar panel cleaning robot, measuring 282 mm in length, designed to house essential components such as motors, batteries, and control electronics. The chassis includes precisely drilled mounting holes: a 28 mm PCD with four 3.2 mm holes for motor or bearing mounts, 10.2 mm and 5.2 mm holes for axles or fasteners, and slots for structural integration shown in Fig 3.14. The design ensures balanced load distribution, rigidity, and ease of assembly. A 3D isometric view highlights its rectangular open-box structure, ensuring accessibility and component protection, making it suitable for lightweight and efficient robotic applications.

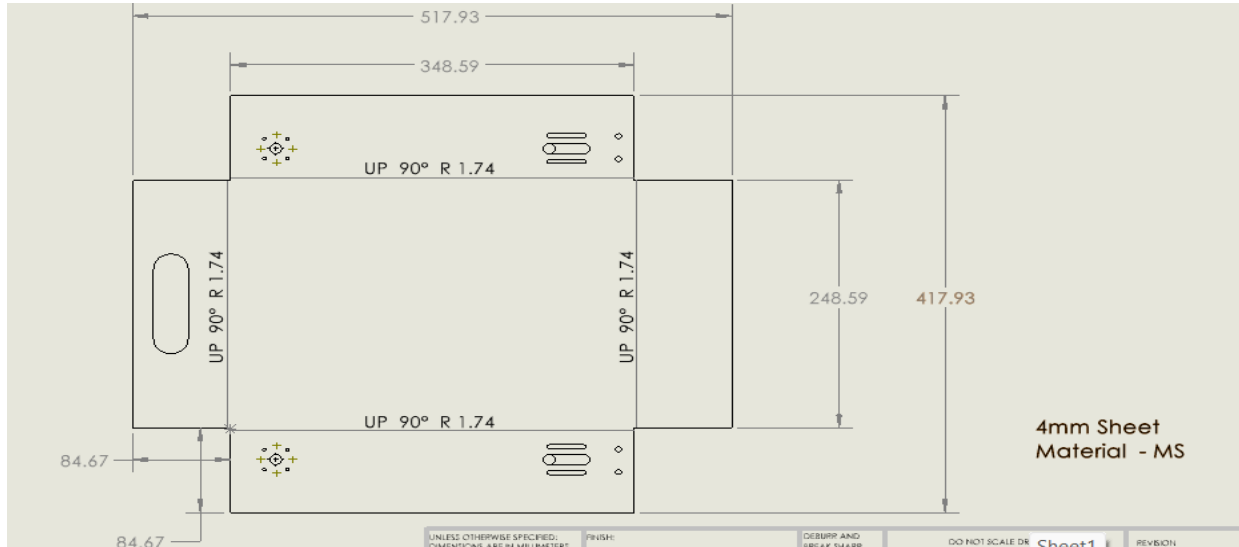


Fig 3.15 Base Flaten Drawing

3.4.2 Driver Pulley

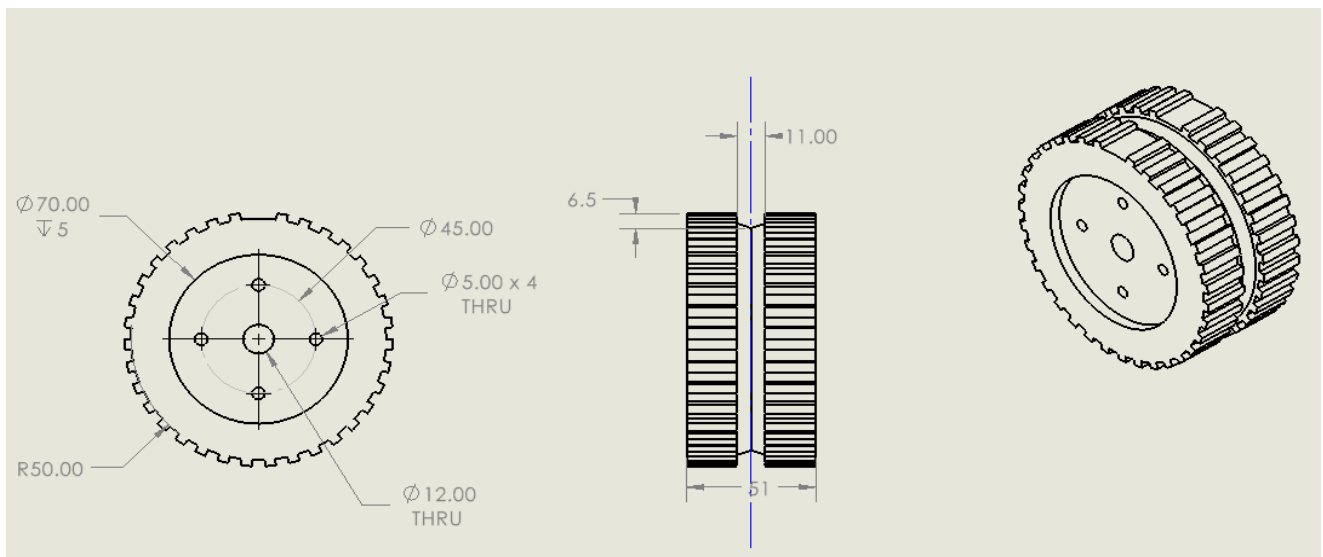


Fig 3.16 Driver Pulley Drawing

The driver pulley shown in Fig 3.16 is a precision-machined component designed to transmit torque from the motor to the belt-driven system of the solar panel cleaning robot. With a 70 mm outer diameter and toothed profile, it ensures slip-free power transmission. The pulley features a 12 mm central bore for shaft mounting, four 5 mm through holes on a 45 mm PCD for secure coupling, and a 51 mm overall width. A central recess and 6.5 mm flange provide alignment and belt stability. This robust pulley is crucial for translating motor rotation into linear brush or wheel movement, enhancing cleaning efficiency and control.

3.4.3 Driver Pulley Hub

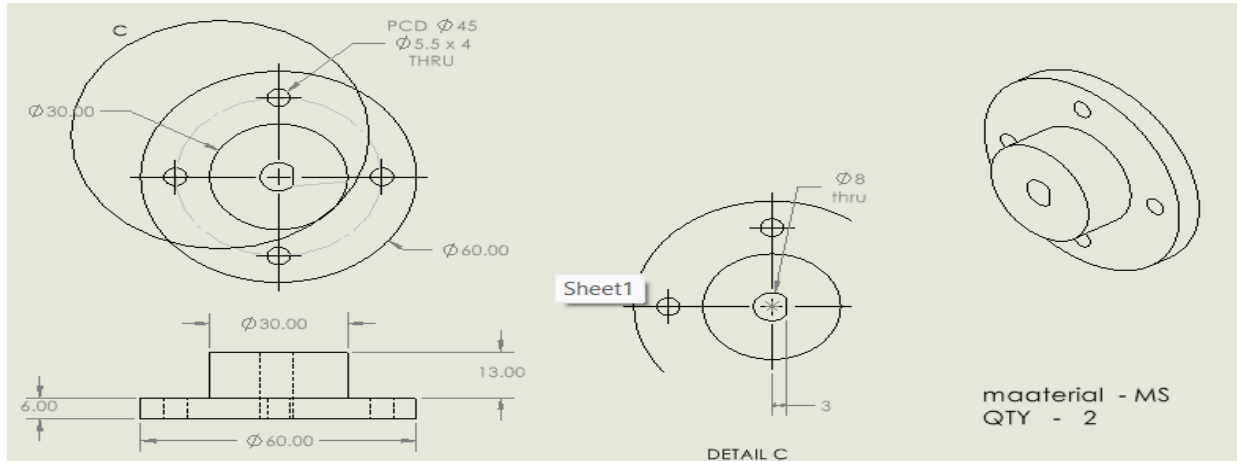


Fig 3.17 Pulley Hub Drawing

The driver pulley hub shown in Fig 3.17 is a mild steel (MS) coupling component designed to securely connect the motor shaft to the driver pulley. It features a 60 mm outer flange with four 5.5 mm through holes on a 45 mm pitch circle diameter for bolting the pulley. The central hub has a 30 mm bore, 13 mm depth, and an 8 mm through-hole for shaft securing, possibly via a set screw or key. With a stepped profile and robust construction, it ensures precise torque transmission between the motor and pulley, minimizing vibration and slippage during operation in the solar panel cleaning mechanism.

3.4.4 Driven Pulley

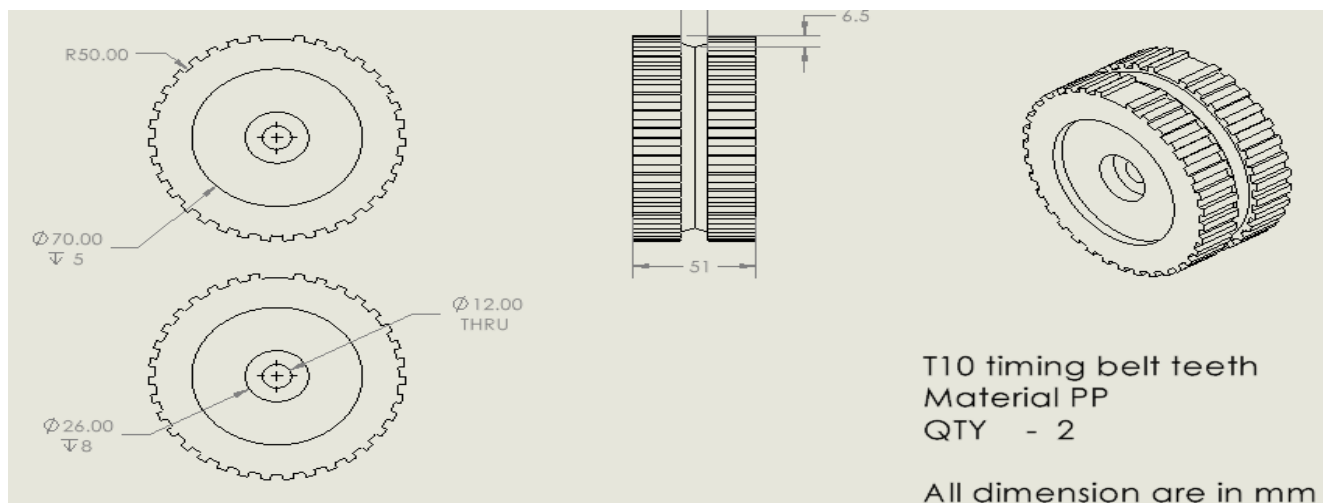


Fig 3.18 Driven Pulley Drawing

The driven pulley shown in Fig 3.18 is a critical component in the solar panel cleaning robot's belt transmission system, responsible for transferring motion to the cleaning mechanism. Made of polypropylene (PP) for lightweight and corrosion resistance, it features T10 timing belt teeth for precise, non-slip engagement with the belt. The pulley has a 70 mm outer diameter, 12 mm central through-hole for shaft mounting, and a 51 mm width for stable belt alignment. The integrated shaft allows it to rotate smoothly with the driven load. Its toothed profile ensures accurate torque transfer, making it ideal for low-maintenance, efficient cleaning operations on solar panel surfaces.

3.4.5 Driven Pulley Shaft

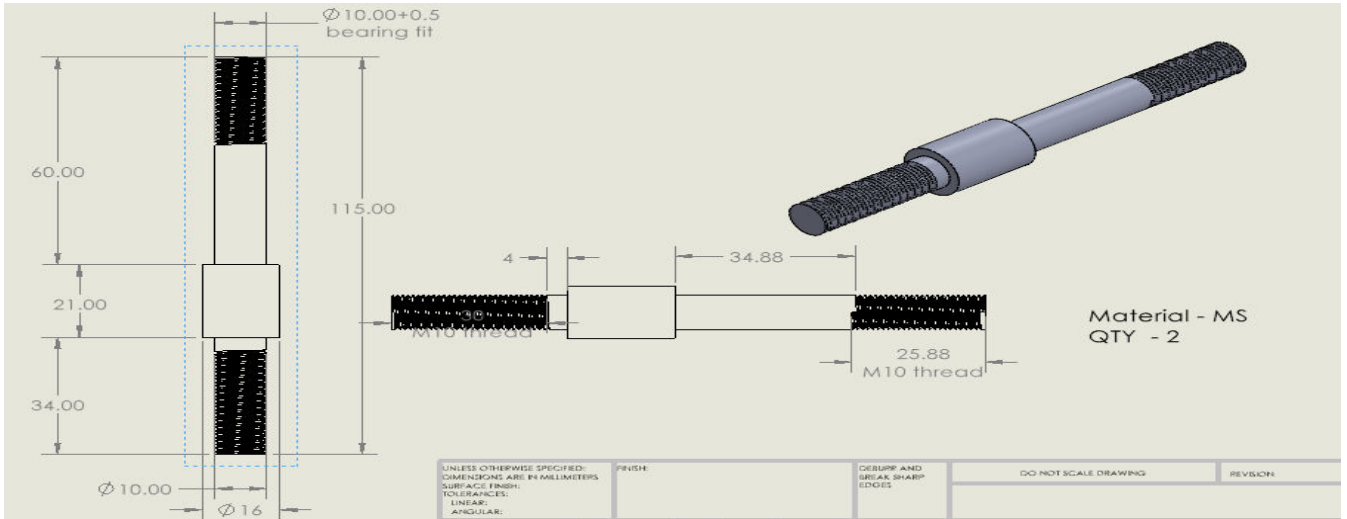


Fig 3.19 Pulley Shaft Drawing

The driven pulley shaft shown in Fig 3.19 is a robust mechanical element made from mild steel (MS), designed to support and transmit motion from the driven pulley to the cleaning mechanism. It measures 115 mm in total length and includes precision-machined sections: a 10 mm diameter bearing fit zone for smooth rotation, M10 threaded ends for secure fastening, and a central 16 mm diameter collar for driven pulley mounting. With a balanced design for load-bearing and alignment, it ensures stable torque transmission while minimizing vibration. This shaft is vital for enabling effective cleaning arm rotation in the solar panel cleaning robot's drivetrain system.

3.4.6 Base to Profile Connector

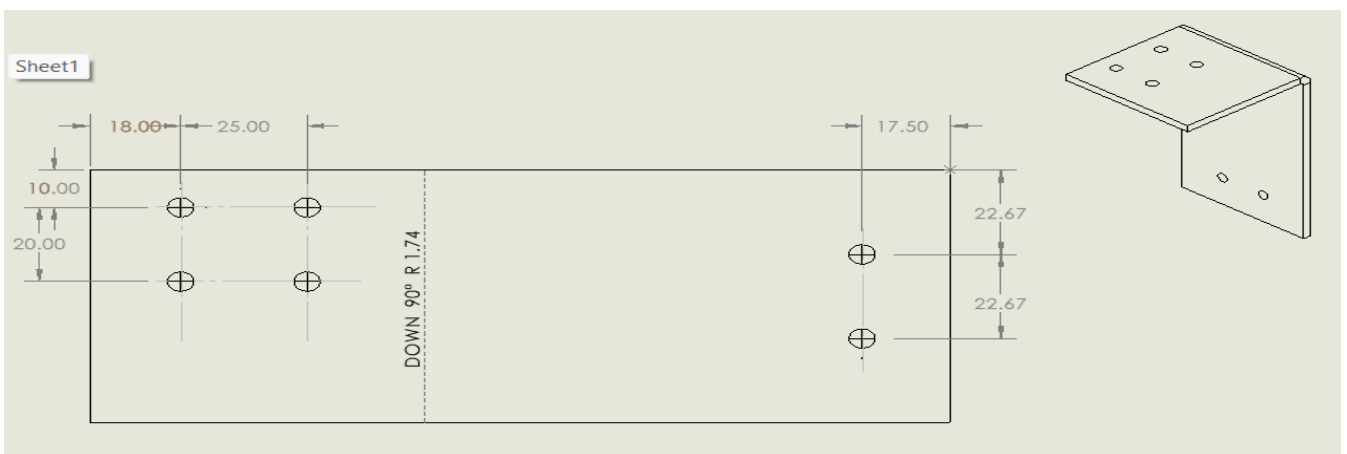


Fig 3.20 Base To Profile Connector Drawing

The base to profile connector shown in Fig 3.20 is a right-angle metal bracket used to mount a 2040 aluminum profile frame to the robot's base. It features multiple precisely spaced 5 mm holes for secure bolting: four on the vertical flange and two on the horizontal, ensuring a firm, vibration-resistant attachment. The bracket has a bend radius of 1.74 mm and an overall layout optimized for structural alignment. Made from durable sheet metal, it maintains the frame's perpendicularity while supporting operational loads. This connector plays a critical role in unifying the chassis and frame structure of the solar panel cleaning robot.

3.4.7 Profile Connector

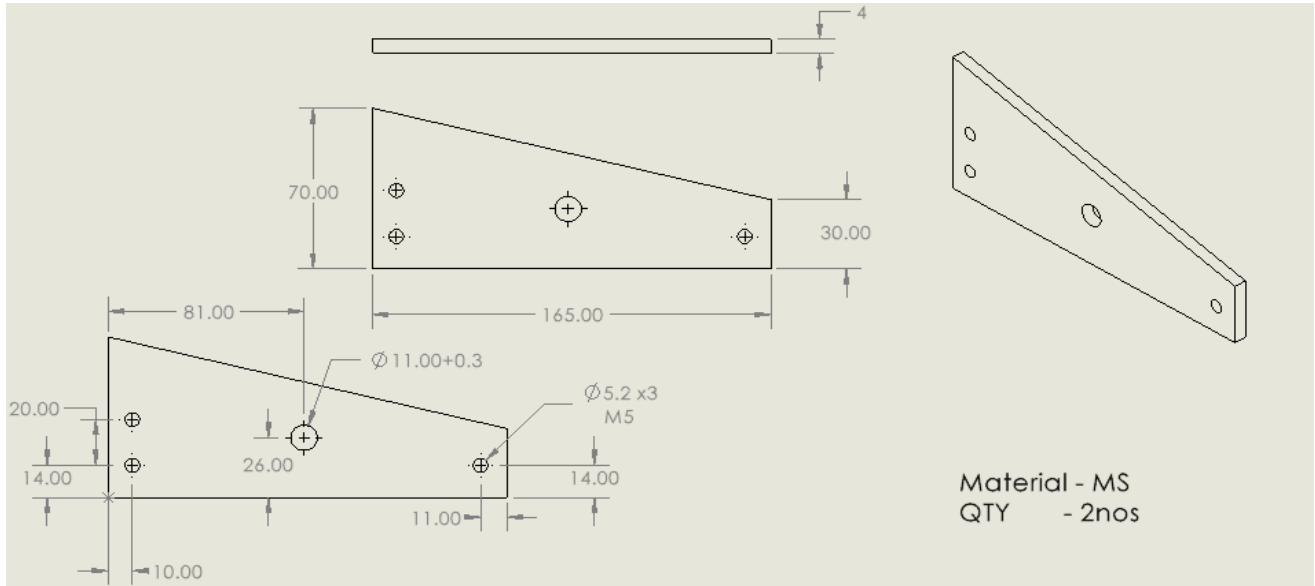


Fig 3.21 Profile Connector Drawing

The profile connector shown in Fig 3.21 is a mild steel (MS) bracket designed to structurally join 2020 and 2040 aluminum profiles in the solar panel cleaning robot's frame. With a slanted rectangular geometry, it ensures angled, rigid connections between profiles. It includes three 5.2 mm diameter holes for M5 fasteners and one central 11 mm hole for additional mounting. The 165 mm length and 70 mm maximum height provide a wide surface area for strong joints. This component improves frame integrity, aligning different-sized profiles precisely and enabling secure load distribution across the chassis during operation.

3.4.8 Brush Pulley Shaft

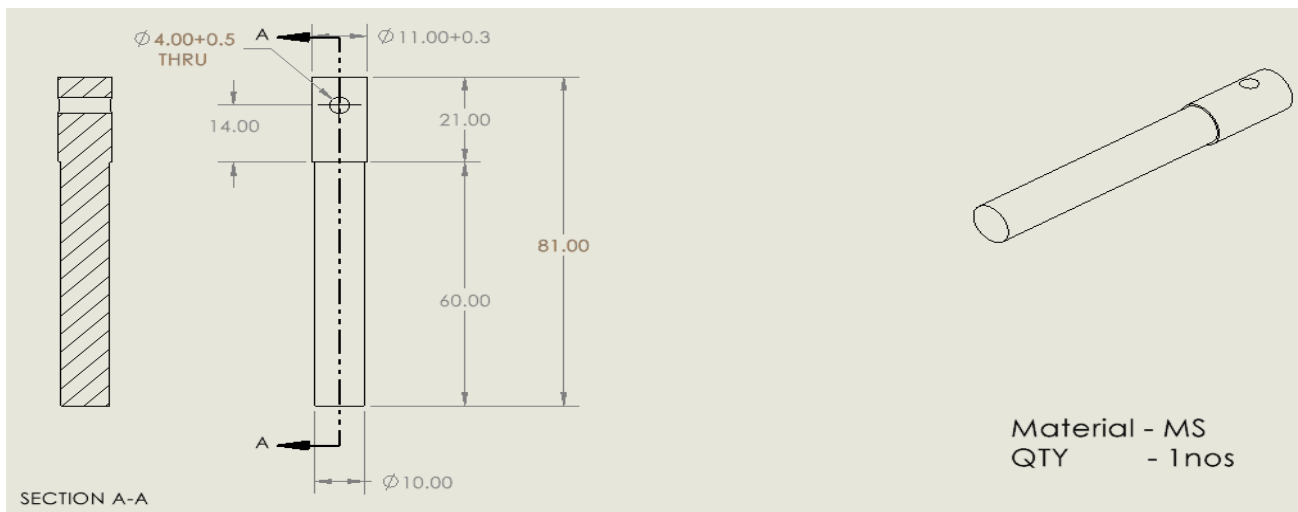
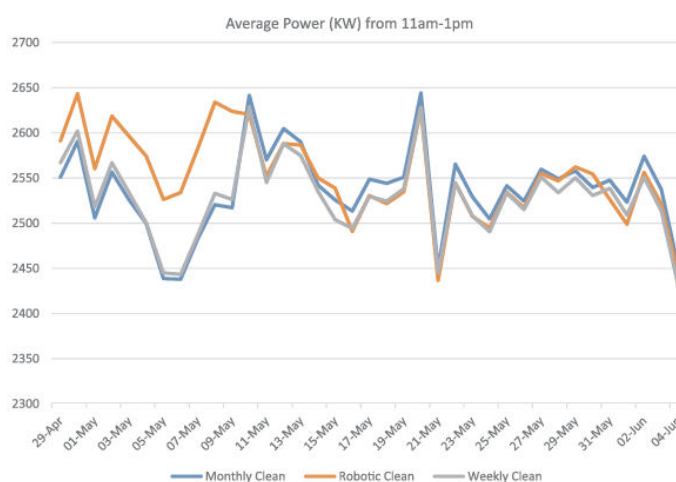


Fig 3.22 Brush Pulley S

IV. RESULT

Cleaning Analysis On Pv The cleaning analysis of the IoT-controlled solar panel cleaning robot was carried out by comparing the panel efficiency under different conditions. Without cleaning, the solar panels operated at only 50% efficiency. Manual cleaning improved this to around 70%, while the robotic cleaning system consistently achieved 85–90% efficiency. This significant improvement demonstrates the robot's effectiveness in removing dust and debris using a soft-brush mechanism and uniform movement across the panel surface. Remote operation through the IoT interface enabled timely, automated cleaning cycles, reducing labor dependency and minimizing the risk of damage, while maintaining high energy output and long-term panel performance.



V. CONCLUSION

A solar panel cleaning robot is an innovative device designed to maintain the efficiency and longevity of solar panels by removing dirt, dust, and debris that accumulate on their surfaces. These robots operate autonomously or semi-autonomously, using advanced sensors, AI, and navigation systems to detect and clean solar panels effectively.

The robot eliminates the need for manual cleaning, which can be labor-intensive, time-consuming, and potentially risky, especially for large-scale solar farms or rooftop installations. Most cleaning robots use waterless or minimal water cleaning methods to conserve resources while ensuring thorough cleaning. Some models are lightweight, portable, and adaptable to various panel types and sizes.

By ensuring that solar panels remain clean, these robots enhance energy output, reduce maintenance costs, and support sustainable energy goals. They are particularly beneficial in dusty regions, where solar panel efficiency is significantly affected by environmental conditions

REFERENCES

- 1."Design and implementation of a waterless solar panel cleaning system" Published in: Unconventional Resources, Volume 5, 2025, Article ID 100131 Published by: KeAi Communications Co. Ltd (Elsevier)
- 2.S. Z. Said, S. Z. Islam, N. H. Radzi, C. W. Wekesa, M. Altimania, and J. Uddin, "Dust impact on solar PV performance: A critical review of optimal cleaning techniques for yield enhancement across varied environmental conditions," Energy Reports, vol. 12, pp. 1121–1141, 2024, doi: 10.1016/j.egy.2024.06.024.
3. N. M. Kumar, K. Sudhakar, M. Samykano, and S. Sukumaran, "Dust cleaning robots (DCR) for BIPV and BAPV solar power plants – A conceptual framework and research challenges," Procedia Computer Science, vol. 133, pp. 746–754, 2018. doi: 10.1016/j.procs.2018.07.123.

4. B. Parrott, P. Carrasco Zanini, A. Shehri, K. Kotsovos, and I. Gereige, "Automated, robotic dry-cleaning of solar panels in Thuwal, Saudi Arabia using a silicone rubber brush," *SolarEnergy*, vol. 171, pp. 526–533, 2018. doi: 10.1016/j.solener.2018.06.104.
5. M. G. Antonelli, P. Beomonte Zobel, A. De Marcellis, and E. Palange, "Autonomous robot for cleaning photovoltaic panels in desert zones," *Mechatronics*, vol. 68, p. 102372, 2020. doi: 10.1016/j.mechatronics.2020.102372.
6. J. F. Derakhshandeh, R. AlLuqman, S. Mohammad, H. AlHussain, G. AlHendi, D. AlEid, and Z. Ahmad, "A comprehensive review of automatic cleaning systems of solar panels," *Sustainable Energy Technologies and Assessments*, vol. 47, p. 101518, 2021. doi: 10.1016/j.seta.2021.101518.
7. N. Ezra, A. Cohen, and D. Zarrouk, "Modeling, simulation, and experiments of a flexible track robot over rigid horizontal and inclined surfaces," *Mechanism and Machine Theory*, vol. 199, Art. no. 105689, 2024.
8. X. Lu, Q. Zhang, and J. Hu, "A linear piezoelectric actuator based solar panel cleaning system," *Energy*, vol. 60, pp. 401–406, 2013, doi: 10.1016/j.energy.2013.07.058.
9. Al Shehri, A., Parrott, B., Carrasco, P., Al Saiari, H., Taie, I., 2017. Accelerated testbed for studying the wear, optical and electrical characteristics of dry cleaned PV solar panels. *Sol. Energy* 146, 8–19. <http://dx.doi.org/10.1016/j.solener.2017.02.014>. Al Shehri, A., Parrott, B., Carrasco, P., Al Saiari, H., Taie, I., 2016.
10. Al Shehri, A., Parrott, B., Carrasco, P., Al Saiari, H., Taie, I., 2016. Impact of dust deposition and brush-based dry cleaning on glass transmittance for PV modules applications. *Sol. Energy* 135, 317–324. <http://dx.doi.org/10.1016/j.solener.2016.06.005>.
11. Alshehri, A., Parrott, B., Outa, A., Amer, A., Abdellatif, F., Trigui, H., Carrasco, P., Patel, S., Taie, I., 2014. Dust mitigation in the desert: cleaning mechanisms for solar panels in arid regions, in: 2014 Saudi Arabia Smart Grid C
12. Chu, S., Cui, Y., Liu, N., 2016. The path towards sustainable energy. *Nat. Mater.* 16, 16–22. <http://dx.doi.org/10.1038/nmat4834>.
13. Costa, S.C.S., Sonia, A., Diniz, A.C., Kazmerski, L.L., 2016. Dust and soiling issues and impacts relating to solar energy systems: literature review update for 2012–2015. *Renew. Sustain. Energy Rev.* 63, 33–61. <http://dx.doi.org/10.1016/j.rser.2016.04.059>.
14. Creutzig, F., Agoston, P., Goldschmidt, J.C., Luderer, G., Nemet, G., Pietzcker, R.C., 2017. The underestimated potential of solar energy to mitigate climate change. *Nat. Energy* 2. <http://dx.doi.org/10.1038/nenergy.2017.140>.
15. Deb, D., Brahmabhatt, N.L., 2017. Review of yield increase of solar panels through soiling prevention, and a proposed water-free automated cleaning solution. *Renew. Sustain. Energy Rev.* 0–1. <http://dx.doi.org/10.1016/j.rser.2017.10.014>.
15. Hallegatte, S., Rogelj, J., Allen, M., Clarke, L., Edenhofer, O., Field, C.B., Friedlingstein, P., Van Kesteren, L., Knutti, R., Mach, K.J., 2016. Mapping the climate change challenge. *Nat. Publ. Gr.* 6, 663–668. <http://dx.doi.org/10.1038/nclimate3057>.
16. IEA, 2016. World Energy Outlook 2016 (Executive Summary). World Energy Outlook 1–8. https://doi.org/http://www.iea.org/publications/freepublications/publication/WEB_WorldEnergyOutlook2015ExecutiveSummaryEnglishFinal.pdf. Jacobson, M.Z., Delucchi, M.A., Cameron, M.A., Frew, B.A., 2015.
17. Jacobson, M.Z., Delucchi, M.A., Cameron, M.A., Frew, B.A., 2015. Low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes. *Proc. Natl. Acad. Sci.* 112, 15060–15065. <http://dx.doi.org/10.1073/pnas.1510028112>.



INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 9940 572 462  6381 907 438  ijirset@gmail.com



www.ijirset.com

Scan to save the contact details