SOLAR PANEL CLEANING SYSTEM

Project ID. 2023: 111

Session: BSc. Fall 2019

Project Supervisor: Lec. Abdul Basit Taj

Submitted By

Muhammad Arslan Janjua

Fahad Ahmad

Muhammad Saad Ashfaq

Electrical Engineering Department

National University of Technology (NUTECH)

Islamabad, Pakistan

2023

Certification

This is to certify that Muhammad Arslan Janjua, Reg.No. F19603006, Muhammad Saad Ashfaq, Reg.No. F19603025 and Fahad Ahmad, Reg.No. F19603035, have successfully completed the final project Solar Panel Cleaning System**,** at the **National University of Technology,** to fulfill the partial requirement of the degree **BS of Electrical Engineering.**

External Examiner

[Name of Examiner]

[Designation]

Project Supervisor

Lec. Abdul Basit Taj

Lecturer

Dean of University

Electrical Engineering Department, National University of Technology

Sustainable Development Goals

SDG No	Description of SDG	SDG No	Description of SDG
SDG 1	No Poverty	SDG 9 ✓	Industry, Innovation, and Infrastructure
SDG 2	Zero Hunger	SDG 10	Reduced Inequalities
SDG 3	Good Health and Well Being	SDG 11	Sustainable Cities and Communities
SDG 4	Quality Education	SDG 12	Responsible Consumption and Production
SDG 5	Gender Equality	SDG 13	Climate Change
SDG 6	Clean Water and Sanitation	SDG 14	Life Below Water
SDG 7	Affordable and Clean Energy	SDG 15	Life on Land
SDG 8 ✓	Decent Work and Economic Growth	SDG 16	Peace, Justice and Strong Institutions
		SDG 17	Partnerships for the Goals

Range of Complex Problem Solving			
	Attribute	**Complex Problem**	
	Range of conflicting requirements	Involve wide-ranging or conflicting technical, engineering and other issues.	
	Depth of analysis required	Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models.	
	Depth of knowledge required	Requires research-based knowledge much of which is at, or informed by, the forefront of the professional discipline and which allows a fundamentals-based, first principles analytical approach.	
	Familiarity of issues	Involve infrequently encountered issues	
	Extent of applicable codes	Are outside problems encompassed by standards and codes of practice for professional engineering.	
	Extent of stakeholder involvement and level of conflicting requirements	Involve diverse groups of stakeholders with widely varying needs.	
	Consequences	Have significant consequences in a range of contexts.	
	Interdependence	Are high level problems including many component parts or sub-problems	
Range of Complex Problem Activities			
	Attribute	**Complex Activities**	
	Range of resources	Involve the use of diverse resources (and for this purpose, resources include people, money, equipment, materials, information and technologies).	
	Level of interaction	Require resolution of significant problems arising from interactions between wide ranging and conflicting technical, engineering or other issues.	
	Innovation	Involve creative use of engineering principles and research-based knowledge in novel ways.	
	Consequences to society and the environment	Have significant consequences in a range of contexts, characterized by difficulty of prediction and mitigation.	
	Familiarity	Can extend beyond previous experiences by applying principles-based approaches.	

Abstract

During the last decade, the usage of solar energy technology has increased tremendously due to the increase in electricity demand all around the world. Solar energy is harnessed using photovoltaic (PV) Panels which are arranged in the form of arrays. Due to the accumulation of dust, debris, and grime (moisture & dust compound), the efficiency of the solar panel decreases in terms of power generation. Loss in power generation will result in fewer electricity units being produced. This emphasizes the significance of keeping solar panel surfaces as clean as possible.

The goal of this project is to create an automated solar panel cleaning system that employs water, wiper, and brush mechanism to clean the panel. We autonomously control the mechanical mechanism using environmental data where the solar system is installed. The data is monitored through an online cloud-based server and is interconnected with an Android app.

Our designed mechanism works and performs its functions adequately on L1-array type solar placement and shed-type solar placement. To clean solar panels arranged in L2 and L3-array type solar placement, the system design must be extended.

Furthermore, the designed system is economical on a larger scale as compared to the cost of solar system installation which produces power in 50KW and above. The cleaning accuracy achieved by our system is about 70%, which is based on the analysis during cleaning.

Undertaking

I certify that the project **Solar Panel Cleaning System** is our own work. The work has not, in whole or in part, been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged/ referred.

[Muhammad Arslan Janjua]

[F-19603006]

[Muhammad Saad Ashfaq]

[F-19603025]

[Fahad Ahmad]

[F-19603035]

Acknowledgement

All the acclamation and appreciations are for Almighty ALLAH who created the universe and bestowed mankind with knowledge and wisdom to search for its secrets.

We would like to express our deep gratitude to Professor Dr. Yasir Awais Butt for his extensive knowledge and expertise in the field of Electrical Engineering. His valuable insights and advice played a crucial role in shaping our project and pushing us toward excellence. His unwavering support and encouragement have been instrumental in our success.

We would also like to extend our sincere appreciation to Lecturer Abdul Basit Taj for his continuous support and dedication throughout the project. His practical expertise and willingness to share his knowledge have been invaluable to our understanding of the subject matter. His guidance and feedback were instrumental in refining our ideas and ensuring the successful implementation of our project. Their availability and willingness to answer our questions and address our concerns were immensely helpful in overcoming the challenges faced during the project.

Finally, we would like to express our gratitude to the entire faculty of the Electrical Engineering Department for providing an environment conducive to learning and innovation. Their dedication to education and commitment to fostering the growth of their students have been truly inspiring.

We are thankful to our parents for their support and cooperation during this project. It was their sincerest prayers and blessings which directed our efforts towards a meaningful cause, that is, the completion of this project.

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IRENA	**INTERNATIONAL RENEWABLE ENERGY AGENCY**

ABSTRACT

During the last decade, the usage of solar energy technology has increased tremendously due to the increase in electricity demand all around the world. Solar energy is harnessed using photovoltaic (PV) Panels which are arranged in the form of arrays. Due to the accumulation of dust, debris, and grime (moisture & dust compound), the efficiency of the solar panel decreases in terms of power generation. Loss in power generation will result in fewer electricity units being produced. This emphasizes the significance of keeping solar panel surfaces as clean as possible.

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Chapter 1

INTRODUCTION

1.1 Background

The generation of energy in Pakistan is heavily reliant on fossil fuels. Due to the large population and industry energy demands, these upwellings are not meeting the demand for the energy needed by Pakistan. Pakistan is in its worst energy crisis.[1][2] Energy demand all around the world has been increasing tremendously in the last decade. Energy demand in Pakistan is increasing annually at a rate of 9%. It is expected that by 2050, energy demand will increase to about 20% annually.[3]
Geographically Pakistan lies on the equator and throughout the year receives a large amount of sunlight. To overcome the energy crises, present in the country, it is necessary to exploit solar energy and other renewable resources available. Public and private sector investment is important for harnessing the true potential of solar energy.[4]
Shaikh et al.[5] stressed the importance of solar energy as a natural asset for Pakistan. Shakeel et al.[6] has reported that the country has an overall solar power potential of 1600,000 MW. Many researchers have found out about the challenges related to solar energy faced in Pakistan.[7][8][3]

1.1.1 Worldwide Solar Energy Consumption

According to the renewable global status report and the International renewable energy agency, the installed capacity of solar systems has increased from 40,000 MW in 2011 to 850,000 MW in 2020 in electricity generation. It is expected to cross the 1 million GWh mark by the end of 2022. solar PV has emerged as a key component in the low-carbon sustainable energy system required to provide access to affordable and dependable electricity, assisting in fulfilling the Paris climate agreement and in achieving the 2030 SDG targets[9]. Figure.1 represents the installation of solar energy worldwide till 2020.

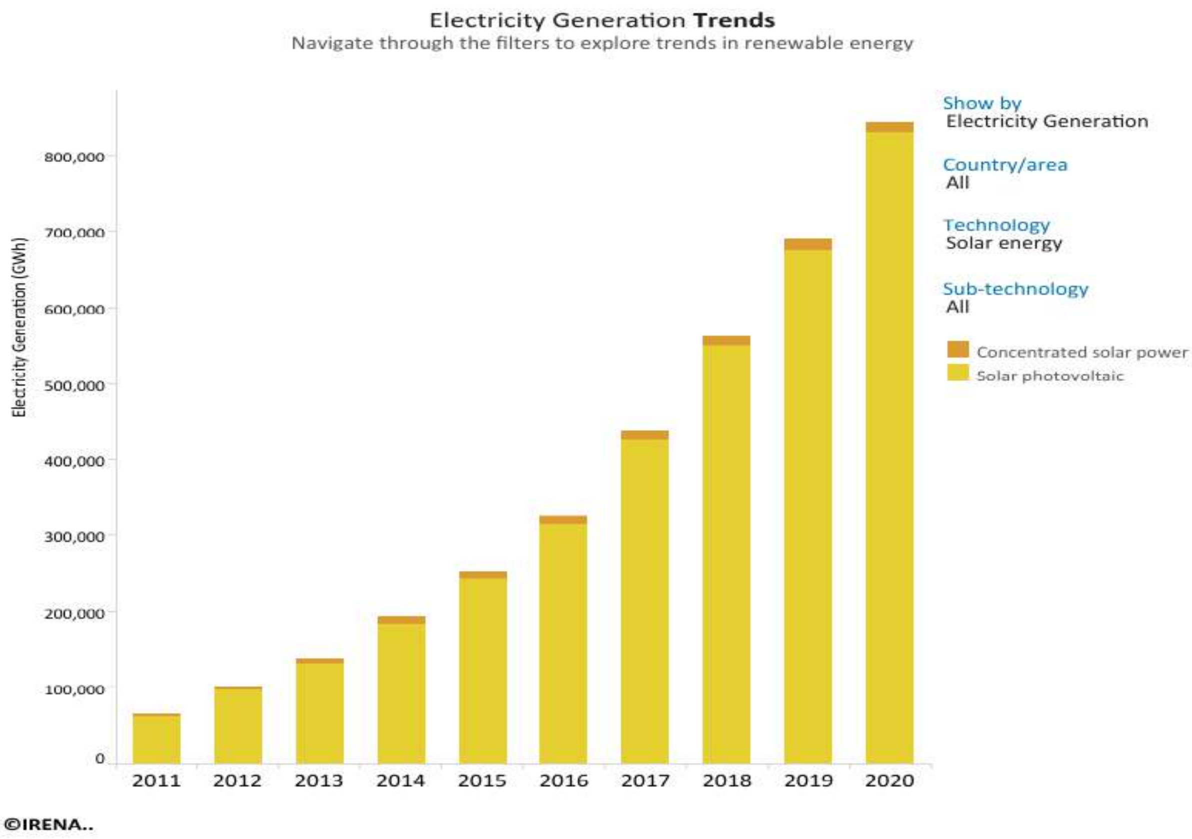


Figure 1.1 Installed Capacity of Solar Energy Worldwide[10]

1.2 Problem Statement

Solar energy has huge potential if people utilize it for sustainable, reliable, and lasting energy production and consumption. Many problems arise with solar systems after they are installed. It is a fact that solar panels available in markets all around the world have an efficiency of 16-22% that converts sunlight into usable power. Now this efficiency is affected by different factors ranging from dust deposition and grimes due to moisture, bird droppings, and partial shading[11]. Other factors that can affect the transplant glass are corrosive gases[12] or natural disasters such as strong wind[13] can also have significant effects on solar panels. The main factor that our project will be dealing with is the dust, grime, and bird droppings. According to a study, the efficiency of solar panels decreases by 15-30% due to dust depending upon the location where the solar system is being installed such as deserts and coastal areas.[14] Depending upon the location where dust content is large, efficiency will be high and vice versa. The below table shows how much losses occur in different residential solar systems across Pakistan if they are placed in an environment having high dust content. The data below is calculated keeping in mind that the solar system uses a 540W solar panel or any equivalent. One unit of energy in Pakistan cost about 30 rupees according to WAPDA and this price may vary over time.

Type Of Solar Systems (KW)	Total Wattage (W)	Losses due to Dust at 30% (W)	Remaining Wattage after Loss(W)	Units produced daily at maximum capacity (KWh)	Units produced daily after losses (KWh)	Financial losses (Rupees)
5	5940	1780	4160	20	16	3600
10	10260	3078	7182	40	30	90000
15	15120	4536	10464	60	40	18000

Table 1 Power Losses in Term of Financial Cost Analysis

The data shown in the above table may not seem to be creating a tremendous impact on small residential systems where electricity is used on a small daily basis because, in the long term, such losses are elusive and could financially have provided a person with greater reliability and sustainability on their instilled system. In large-scale solar systems, huge financial losses in terms of power generation could have made utility companies corpus the amount of cash that is lost due to no regular cleaning of Solar panels. So, cleaning Solar panels is necessary to maintain efficiency in terms of power generation.

1.2.1 Soiling issue

Atmospheric dust and soiling significantly reduce the performance of solar modules. Soiling is an issue caused by the deposition of dust on solar modules.[15] Atmospheric dust may absorb solar radiation, but soiling can degrade solar modules. The power generated by solar panels depends upon the amount of irradiance. Soiling reduces the irradiance absorbed by a solar panel. Researchers have concluded that soiling plays a tremendous role in reducing the energy generation of solar power plants.[16]

1.3 Aims and Objectives

This Project aims to develop a sustainable, reliable, and easy-to-use system dedicated to cleaning solar panels across any type of solar arrangement. The designed system should meet the following objectives:

- System should be able to move across the panels in both forward and reverse directions.
- The system would also have a wiper, brush, and water sprinkling mechanism installed in it.
- The water sprinkling Mechanism should be able to control the flow of water.

1.4 Applications of the Project

This Project is aimed at developing a cleaning solution dedicated to solar panel cleaning. The scope of this research is:

- Maximize Energy Production: Solar panels operate most efficiently when they are clean and free from dirt, dust, bird droppings, and other debris. Regular cleaning using automated cleaning systems ensures optimal sunlight absorption and maximizes energy production.
- Improve System Performance: Accumulated dirt or dust on solar panels can reduce their overall performance. By removing these contaminants, cleaning systems help maintain the panels' efficiency and output capacity, ensuring the system operates at its full potential.
- Cost Reduction: Dirty or partially obstructed solar panels lead to decreased power generation, which can result in reduced financial returns. Cleaning systems help mitigate this issue by preventing energy loss and reducing the need for additional maintenance or panel replacements, resulting in long-term cost savings.
- Maintenance Efficiency: Manual cleaning of large-scale solar installations can be time-consuming and labor-intensive. Automated cleaning systems, such as robotic or waterless cleaning systems, enable efficient and faster cleaning of multiple panels simultaneously, reducing the maintenance workload and associated costs.
- Longevity and Durability: Regular cleaning helps extend the lifespan of solar panels by preventing corrosion and damage caused by environmental factors like dirt, salt, or pollutants. By maintaining the panels in a clean state, the cleaning systems contribute to their long-term durability.
- Environmental Benefits: Clean solar panels have a positive impact on the environment. By optimizing energy production, cleaning systems facilitate the generation of clean, renewable energy, reducing the reliance on fossil fuels and

greenhouse gas emissions.

- Remote Monitoring: Some advanced cleaning systems are equipped with monitoring capabilities that allow operators to remotely track the performance and cleaning needs of solar panels. This enables proactive maintenance and ensures timely cleaning, enhancing overall system efficiency.

1.5 Project Plan

The Project is divided into two phases. Each project phase is stretched over a period of 8 months for completion of various tasks about the solution proposed. Below is the project plans for Phase 1 and Phase 2 respectively.

TASK ID	TASK NAME	START DATE	END DATE	DURATION in days
1	Title Approval	14/11/22	10/12/22	24
2	Literature Review	11/12/22	30/12/22	21
3	Frame Design Review	2/11/22	10/12/22	13
4	CAD SOFTWARES and Types of Transmission to move the Frame	14/11/22	10/12/22	14
5	Motor Driver Design And Ultrasonic Sensor	14/11/22	10/12/22	14
6	Motor and battery Selection	14/11/22	10/12/22	13
7	Frame Design Finalization	14/11/22	10/12/22	6
8	Cad Design of the frame	14/11/22	10/12/22	4
9	Software model Completion	14/11/22	10/12/22	1

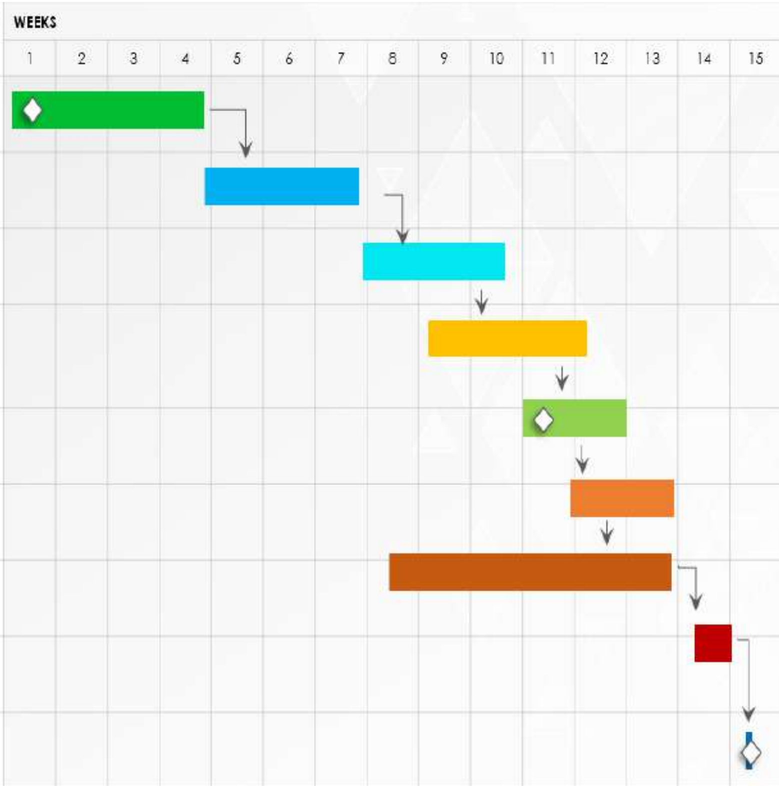
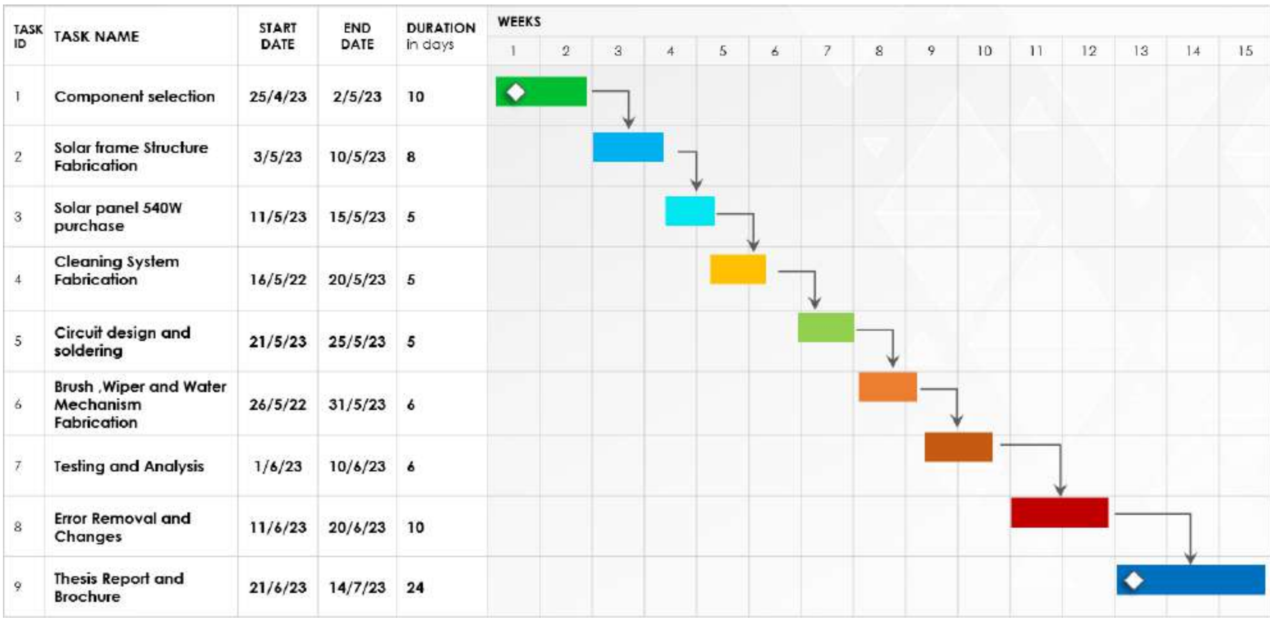


Figure 2 Project Phase 1: Semester 7 Schedule



TASK ID	TASK NAME	START DATE	END DATE	DURATION in days
1	Component selection	25/4/23	2/5/23	10
2	Solar frame Structure Fabrication	3/5/23	10/5/23	8
3	Solar panel 540W purchase	11/5/23	15/5/23	5
4	Cleaning System Fabrication	16/5/22	20/5/23	5
5	Circuit design and soldering	21/5/23	25/5/23	5
6	Brush ,Wiper and Water Mechanism Fabrication	26/5/22	31/5/23	6
7	Testing and Analysis	1/6/23	10/6/23	6
8	Error Removal and Changes	11/6/23	20/6/23	10
9	Thesis Report and Brochure	21/6/23	14/7/23	24

Figure 3 Project Phase 2: Semester 8 Schedule

1.6 Report Organization

This research is organized into six chapters as given in detail below:

Figure 4 Report Organization Flow Chart

Chapter 2

LITERATURE REVIEW

The idea for a solar panel cleaning system was conceived through the increasing energy demand in Pakistan. For such an idea to be given a completely applicable shape, we need to understand how different cleaning technologies work and people around the world have made solar panel cleaning systems and different technologies employed to clean solar panels.

2.1 Solar Panel Cleaning Current technologies and Practices

2.1.1 Current Technologies

Large-scale solar farms or projects are deployed in deserts or places where sunlight remains for 8-10 hours during the day. In such environments where issues like soiling, moisture, and dust build-up on solar panel surfaces cause a huge rift in the power generation capacity of solar plants. To avoid such issues, both traditional and modern cleaning solutions are being used in industry to clean solar panels. Due to the advancement of materials and robotics, traditional methods such as manual cleaning of solar panels are going to be obsolete. Modern solutions such as robotics, cleaning kits, etc. are available to clean a panel effectively. Rainwater

1. **Manual cleaning**

   Different tools and techniques are used to clean solar panels manually with the help of an operator. The most common type of manual cleaning tools is cleaning kits which include extension poles, carrying bags, brushes, clothes, hose connections, and more[17]. Below picture operator working manually to clean the solar panels.

Figure 5 Manual hand cleaning System

2. **Piezoelectric Systems**

   Piezoelectric actuators are being used in various optical adjustments, biomedical manipulation, space exploration, and other areas due to their high torque to volume ratio, flexible structure, and high positioning precision. Such systems are used to clean solar panels by using water as a cleaning agent and spreading it to a depth of 0.1 to 1 mm during the rarefaction cycle of compression waves. A vacuum is created in liquid during rarefaction called ultrasonic cavity and this cavity sucks the dust from the solar panels.[18] [19] Below figure shows a piezoelectric system used to clean solar panels.

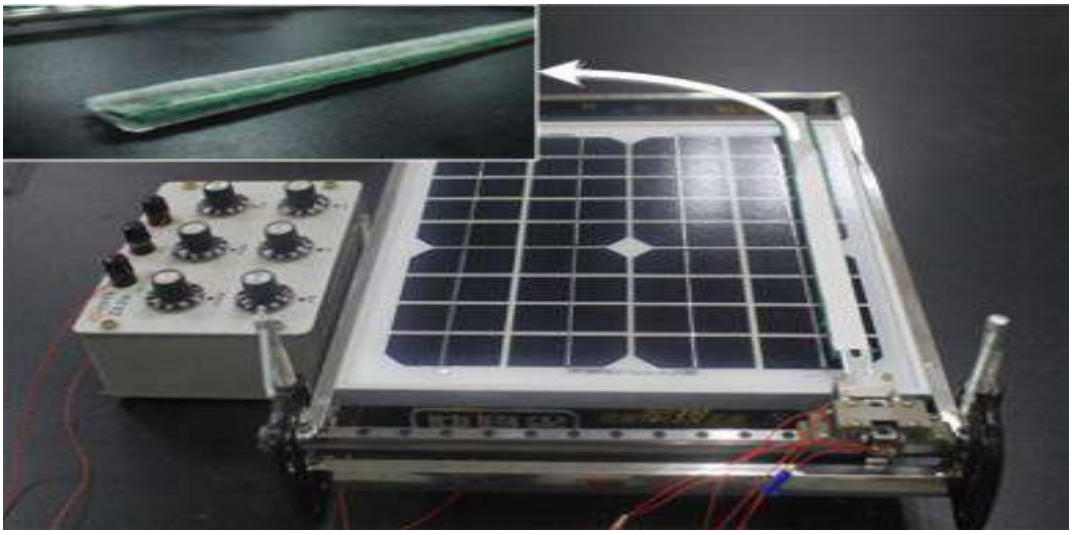


Figure 6 Linear Piezoelectric System

3. **Self- Cleaning Mechanism**

   A translucent self-cleaning nano-film can be coated onto the surface of solar panels to prevent dust deposition. This nano-film is composed of either super-hydrophilic or super-hydrophobic materials. The super-hydrophilicity method relies on rainwater to disperse across the solar module and cleanse the dust particles. However, this approach is not widely adopted due to the limited availability of rainfall in solar farm locations. Alternatively, super-hydrophobic materials facilitate the rapid removal of water droplets, carrying away dust particles like the lotus leaf effect. However, careful examination is needed to assess the practicality of implementing these materials on solar panels, as solar farms are typically situated in regions with infrequent rainfall.[20] [21]

4. **Robotic systems**

   Robotic systems consist of actuators, drivers, and gears having some movement above the solar panel surface, and it is controlled through a virtual operator. The rise of the Internet of Things and fuzzy logic has allowed engineers to develop robotic solar cleaning systems capable of cleaning dust and other excrement of panel surfaces. Robotic units act as slave units and perform the cleaning as commanded by the autonomous unit.

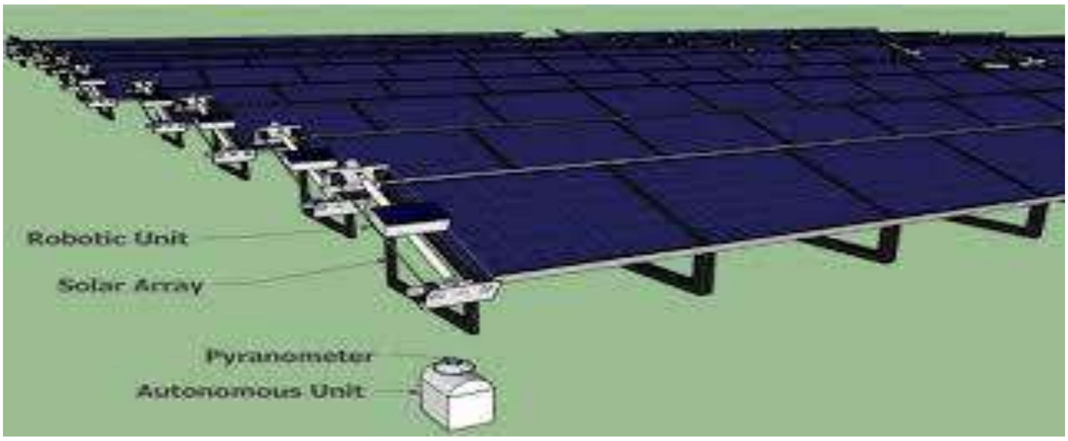


Figure 7 Smart solar panel cleaning System[22]

2.1.2 Current Practices

Mostly cleaning of solar panels is done in two ways: either using water solvent cleaning agents or without water using special brushes. Nowadays most solar panel practices involve a robotic system that incorporates above mentioned practices. The selection of practices may change depending upon the location, and seasonal variations in the area where solar plants are deployed.

1. **Water-based robotic cleaning system**
   These systems use water as a primary component for cleaning solar panels. Water-based systems are suited in urban and tropical climates where is abundantly available. The Serbot Swiss innovations developed a cleaning mechanism for mobile deployment onto SPV panels. This system cleans through a rotating brush and demineralized water. The designed system is controlled via a radio and is easy to move from one to place to another.[23] below shows the figure for the gecko solar panel cleaning system.

Figure 8 Gecko solar robot[23]

2. **Waterless Robotic Cleaning System**
   Though water-based is a more effective cleaning method in dry places such as the desert where there is no availability of water. In waterless cleaning technology, a

brush is used as a dust repellent to wipe the dust from the solar panels. Aerial Power's Solar Brush drone is targeting desert regions of the world[24]. Similarly, the Boson solar panel cleaning robot shown in Figure 8, is a fully automated robot that can clean the surface of solar panels without the use of water.

Figure 9 Boson Robotic Panel Cleaning System[25]

2.2 Projects Related to Solar Panel Cleaning System.

2.2.1 Automatic Solar Cleaning System For Dust Removal [26]

The project under discussion uses two-step cleaning techniques. Firstly, an exhaust fan removes dust from solar panels quickly. And the second step involves a wiper with a soft cloth to wipe the panel surface. The main components used in the project are Microcontroller Arduino Uno, a Dc gear motor, Buck-Boost Converter, and Motor Drive Module. In this project, researchers have used four different types of dust to demonstrate the cleaning process. Such a system is applicable in areas having high environmental dust such as deserts or semi-arid areas.

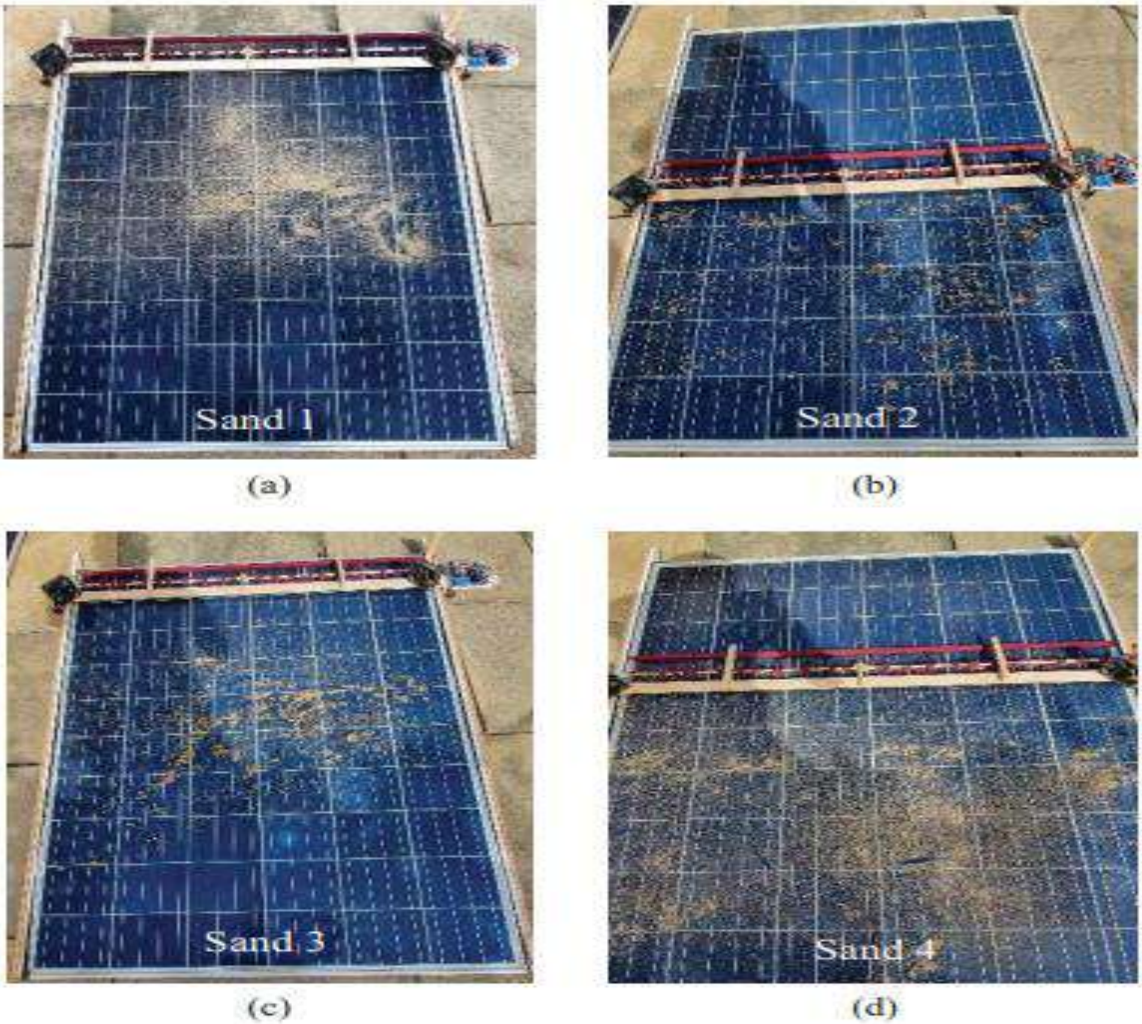


Figure 10 Different Types of Sand Used for Experimental Test [26]

2.2.2 Novel Dry Cleaning Machine [27]

The solution proposed in this paper consists of three separate cleaning mechanisms which are used one after the other in the cleaning process. In the first stage, compressed air is sprayed on the panel with the help of a nozzle to clean dust and remove sand. Limit switches are used at both ends of the panel to signal the completion of a specific stage. In the second stage, the machine moves back to its initial starting point. For this low-density flexible polyurethane foam roller is used to wipe the surface of the panel. In the third stage, the compressor sprays air to remove any dust that remains after the roller moves over its surface. Figure 10 shows how the system makes the algorithm work and what functions are performed by the system in a specific order. Figure 11 shows the prototype for a Novel dry-cleaning Machine for solar panels.

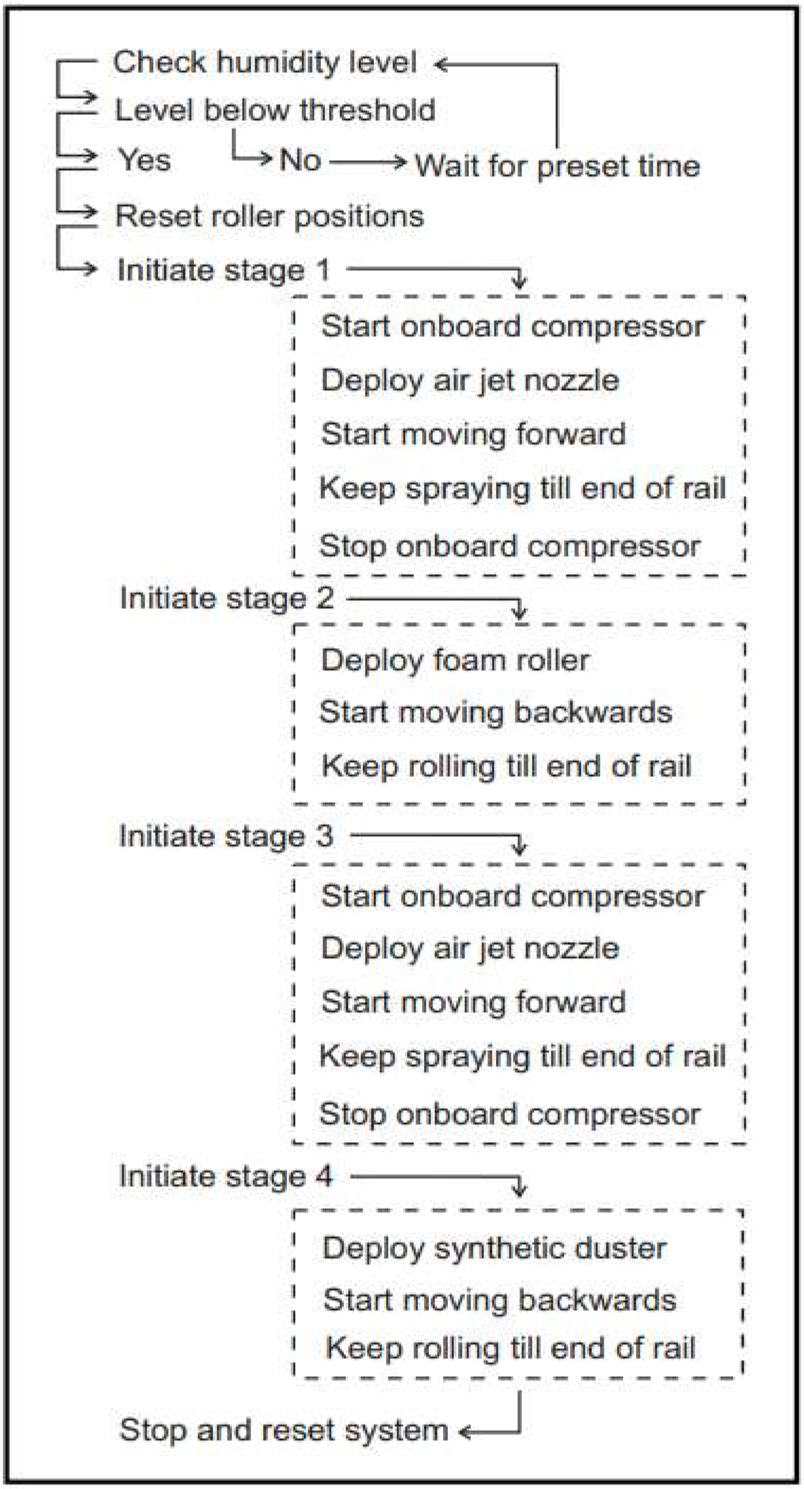


Figure 11 Flow Chart for Four Stages Automatic Dry-Cleaning System

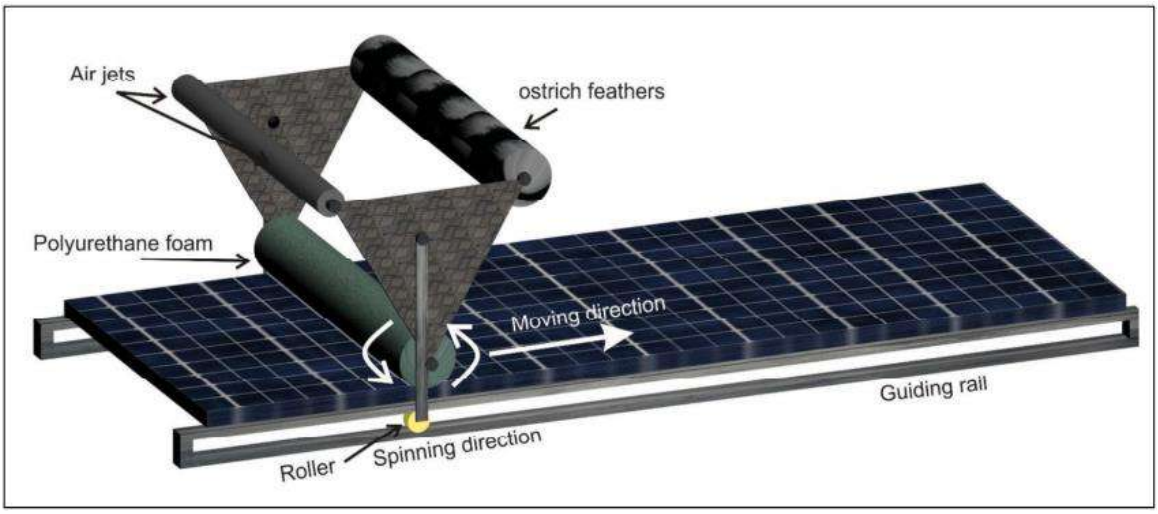


Figure 12 Dry Automatic Cleaning System Overview[27]

2.2.3 Cleaning Robot For Solar Panels[28]

The cleaning Robot uses 5 dc motors from which 2 motor acts as horizontal drives along the row level of solar panels, while 2 motor acts as vertical drives (up and down movement) on the solar panel. The last dc motor is used to rotate the microfiber component that cleans and maintains stability in the vertical motion of the robotic system. The ultrasonic sensor is used to measure the distance traveled by the robot across the panel surface. Figure 12 shows the Prototype design and view of hardware moving on the solar panel.

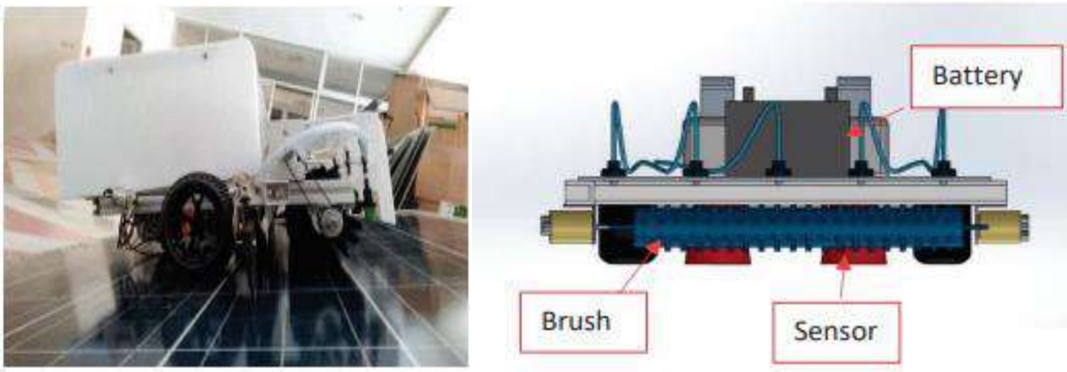


Figure 13 Cleaning Robot Prototype and Hardware[28]

2.2.4 Smart Solar Photovoltaic Panel Cleaning System

The proposed model in this paper utilizes two different controlling units: A robotic Unit and Autonomous Unit that communicate through an internet Cloud-based platform known as UBIDOTS. The robotic unit acts as a slave of the autonomous unit and UBIDOTS interface directly under the operator's command. The robotic unit moves the frame across the solar panel. Two limit switches are used to detect the start and end of solar panels.
The autonomous unit commands the robotic unit to perform the cleaning on the solar panel. It also contains different sensors to sense humidity, temperature and light intensity, dust density, and output power to automate the cleaning process. Figure 13 shows the robotic unit for the above-mentioned system in running condition.

Figure 14 Robotic Unit: Fabricated Prototype[29]

2.3 Limitations

2.3.1 Current Technologies and Practices Limitations

Both current technologies and Practices related to solar cleaning have numerous advantages and disadvantages. Since many solar cleaning systems are designed according to the location of solar placements. Some of the limitations are as follows:

1. Most water-based systems are utilizing large amounts of water as a cleaning solvent. Clean water availability all around the world is becoming a major issue.
2. Traditional cleaning method that requires manual labor and technicians for cleaning purposes. It is a time-consuming process.
3. Piezoelectric cleaning systems are not viable for large-scale solar farms.
4. Self-cleaning of solar panels is dependent upon rainfall. In areas with less rainfall, self-cleaning is not viable.
5. Water-Based Robotic systems are moveable on the panel surface, but the length of the water pipe can be expensive in large solar plants.
6. Waterless robotic systems are expensive to make, and they need to be outfitted with various components for control.
7. Waterless robotic systems are mounted on solar surfaces and need to be modified for use in other arrangements of solar panels. (Refer to Figure 8)

2.3.2 Related Projects Limitations

Many engineers and researchers have designed different types of solar cleaning systems. They have incorporated a variety of solutions and components to design such cleaning systems. Depending upon different solutions, limitations related to the above projects are as follows:

1. Using only brushes to clean solar panels is less effective as compared to water-based systems.
2. Initial investment to deploy such projects on large solar farms or plants is very high.

3. The robotic technology used in above mentioned projects is new and a lot of research and development is required.
4. Most of the mentioned projects have no scope for customization. The designed systems are difficult to change in size as per the type of solar panels.
5. One of the main drawbacks is the reliability and efficiency of solar cleaning systems as to how many solar panels they can clean each time.
6. When robotic-based cleaning systems are deployed on solar plates, one of the main factors is the weight of the mechanism.
7. If the weight of the mechanism is high, it will put an unnecessary burden on solar plates.
8. Fitting of fixed robotic solar cleaning system on the solar plates on a large scale is a cumbersome process.

2.4 Summary

This chapter discusses the various types of technologies and practices related to the cleaning of solar panels. It also sheds light on different projects done by engineers and researchers in the field of solar cleaning systems for R&D. This chapter promulgates the various solutions and ideas, opinions, and their usage, and advantages in cleaning solar panels. The chapter comprises the limitations of different technologies and projects as discussed above. Now the question arises of how we designed our system keeping in view the drawbacks and limitations of solar cleaning technologies.

Chapter 3

DESIGN AND SOFTWARE SIMULATIONS

3.1 Methodology

Every system made since the dawn of the industrial age comprises both mechanical and electrical components. The systems being designed nowadays are a mixture of power, Communication, and sensory technology. We also utilized the same technology such as power modules, controllers, and sensors for measuring data. The system designed for cleaning of solar panels by us consists of a variety of things ranging from Weight calculations, Motors torque and speed, type of motor Driver used, and sensor used to measure data ranging from environmental factors such humidity, Temperature, atmospheric pressure, etc. and solar panel measurements such as power, Voltage, and Current. The idea behind getting such data is utilized to decide when to clean the solar panel. Mechanical actuators such as limit switches will be used for safety purposes.

3.2 Procedures for Design

To start development of the hardware prototype we need some calculations and simulations of electrical components which are based on the data collected through different research papers and projects that have already been done. We design our system we decided that a 540W solar panel will be used as a reference for our hardware development. The procedure followed throughout the project is given below in steps:

1. We start by comparing different systems and designs previously derived by engineers and researchers.
2. Data taken from literature reviews, research papers, and project reports is used as a base to form our design.
3. Our system consists of two main sections: one of the parts is electrical which controls sensors, motors, and water pump. The other part is mechanical which will consist of a frame structure for the solar panel, a shaft for the wiper, brush, and pump mechanism.
4. Firstly, we need to design the mechanical parts or systems, for this purpose, we need calculations based on the type of material used to design the mechanism.
5. Next step will be an adjustment of the motor with the frame and test runs will be taken to ensure that the frame stays in balance while moving across the solar panel.
6. Limit switches will be attached to the system to start and stop the moving mechanism while it's moving in the forward and reverse direction.
7. The system will be controlled by an ESP 32 Wi-fi Module with a built-in microcontroller.
8. Decision of cleaning will be based on the data which will be collected by the sensor.
9. The data will be monitored in real-time through the internet-based data server.

10. Data will be shown in an app that will have the cloud base server API integrated into it for real-time data monitoring.

3.3 Frame Mechanism Design

The first step to designing our system mechanism will be the calculation of various parameters such as the weight of the frame and how much speed and torque of the motor is needed to move the system across the panel. To calculate the total weight of the moving mechanism we need to know the mechanical parts we will need to be fabricated. The Mechanism includes the following mechanical Parts:

1. Windscreen Wiper weight
2. Roller Brush Shaft
3. Rectangular frame
4. Trolley Tires
5. Water pump weight
6. Battery weight
7. Mechanism Movement Holding Shaft
8. Coupling for tightening Purpose
9. Miscellaneous weight

3.3.1 Weight Calculation

- Water sprinkling Shaft.

Material Used = light aluminum alloy

Density of the material=2650-2800 Kg/m^3

Weight of the Shaft = Density * Volume

Volume of hollow shaft =pi*(R^2 – r^2) *h
= 3.14* ((15mm) ^2 – (30) ^2) * 1034mm
= 4.058 * 10^34 m^3

Weight = density * Volume
= 2650 Kg/m^3 *4.058 * 10^-4 m^3

❖ Weight of the water sprinkling shaft = 1.075 Kg

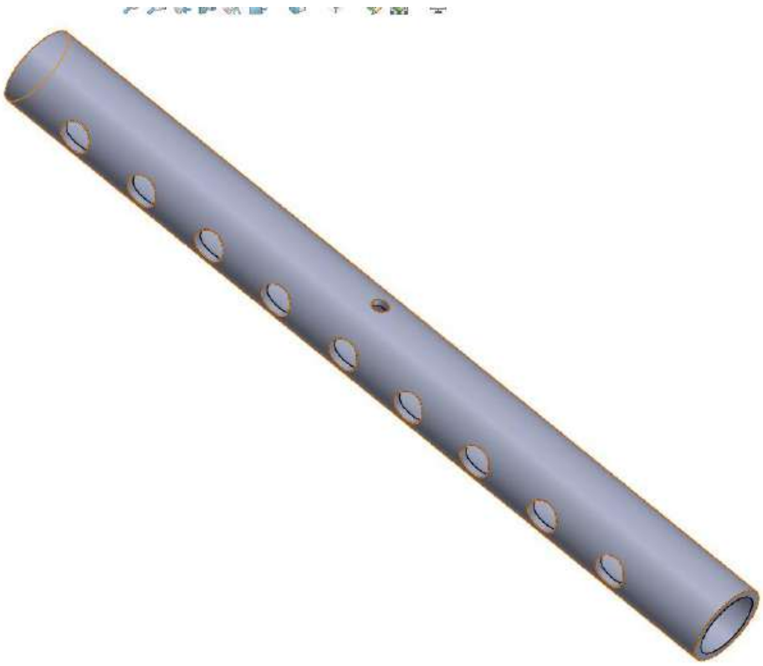


Figure 15 3D Model for Water Sprinkling Shaft

- Nylon Brush Shaft

Density is the same as of aluminum alloy= 2650 Kg/m^3
Volume = pi*r^2*h
= 3.14 * (0.01 m)*2 * 1.034 m
= 3.246 * 10^-4 m^3
Weight = Density ^ Volume
= 0.86019 Kg
Approximately Nylon weigh = .600 Kg

❖ Weight of the Nylon shaft = 0.86019 + 0.600 Kg = 1.5 Kg
Weight may vary if the Nylon material exceeds in quantity.

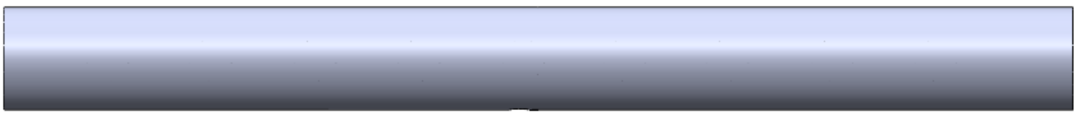


Figure 16 3D Model Nylon Brush Shaft

- Rectangular Frame
  Length = 1134 mm = 1.134 m
  Width = 282 mm = .282 m
  Depth = height = 40 mm = 0.04 m
  Thickness =50 mm = 0.05 m
  Material Used For fabrication = Mild steel/ Aluminum alloy

The density of material = 7.850 / 2650 Kg/m^3

Volume of Outer Section V1 = L * W * H

= 1.134 * .282 *0.04

V1 = .0128 m^3

The Volume of the hollow frame = L-2t * W-2t *H-2t

Volume V2= (1.134 – 2*0.05) * (0.282 -2*0.05) * (0.04 – 2*0.05)

Volume V2= .0112 m^3

Total Volume = V1 – V2

= 0.0128 -0.0112

= 0.0016 m^3

Weight of the rectangular Frame = 7850 Kg/m^3 * 0.0016 m^3

= 12.56 Kg (not Suitable for cleaning system)

For aluminum alloy

- ❖ Weight of the rectangular frame= 2650 Kg/m^3 * .0016 m^3

  = 4.096 Kg

Figure 17 3D Model Rectangular Frame

Due to the large weight which will cause stress upon the edges of the solar panel which can lead to breakage of the transparent tempered glass coating so we replace the rectangular frame with a fixed shaft that will be coupled with a Motor mount in which Dc gear motors will be adjusted for moving the frame across the length of the panel.

- Trolley Tyers weight

  These tires are used to move the frame structure on which the solar panel is placed. So

  - ❖ Weight of the trolley tires = 4* 0.2 Kg = 0.8 kg

Figure 18 3D Model Trolley Tyers

- Wiper Mechanism Weight

Since we are using two windscreen wipers as one of the media to remove dust from the panel, so the approximate weight of both 16-inch and 24-inch windscreen wiper is as follow:

- ❖ Weight of the Wiper Mechanism = .6 Kg

Figure 19 3D Model Windscreen Wiper 24 inch

- Motor Mount Weight

Density of Acrylic=1190Kg/m^3

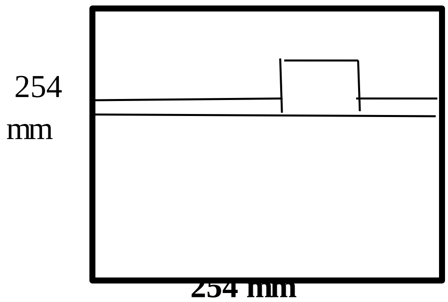


Figure 20 Diagram for Motor Mount

Volume of Motor Mount = 254 mm *254 mm

= 0.254 *0.254 * 0.006

=3.87096 *10^-4 m^3

Weight of single side Motor Mount = Volume * Density

= 3.87096 *10^-4 m^3 * 1190 Kg/m^3

= 0.5 Kg approx.

For both sides of the solar panel, we will have two Motor Mount of the Same Weight so

- ❖ Total Weight of Motor Mount =1 Kg

- Fixed Shaft Coupled with Motor Mount

  The material used = Iron alloy

  The density of Iron alloy

  Approximate weight of a single Hollow rod= 0.8 kg

  For 4 Shaft,

  - ❖ Total weight of Rods= 4 *0.8 Kg =3.2 Kg

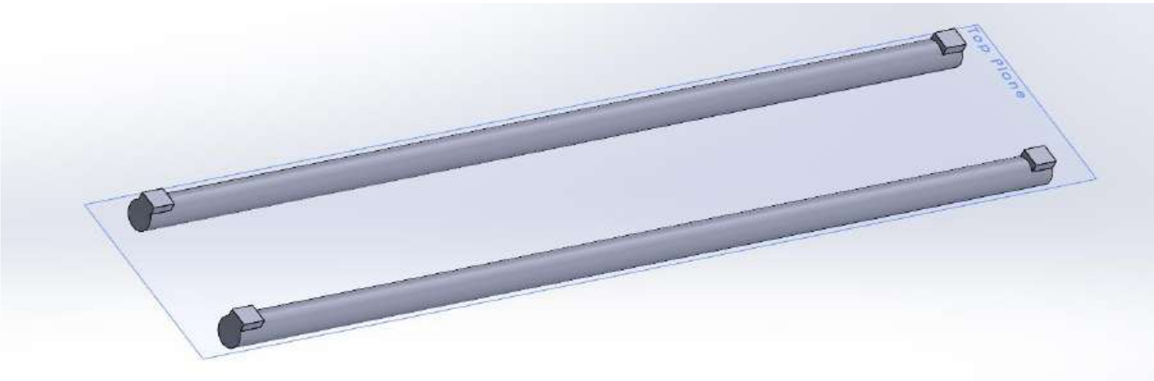


Figure 21 3D Model for Fixed Shafts

- Water Pump Weight

  Weight= 250-300 grams
- Battery 12V 14 Ah – 21 Ah

  Weight of battery = 2.5 kg
- Miscellaneous Components Weight

  These components may include a water pipe, metal coupler and nuts bolts, and other small accessories attached to the system.

  Miscellaneous Weight= 2 Kg

3.3.1.1 Total Weight of the Mechanism

Due to stress upon the solar panel surface, we can only put a maximum weight of amount 20 Kg on the solar panel to avoid breakage of tempered glass, so we neglected the battery and water pump weight. The main reason is that both components are not viable to be attached to the mechanism in the long term due to the charging of the battery and placement of the water pump in the water can become an issue.

Total Weight of the Mechanism = weight of Nylon brush Shaft + Weight of Motor Mount + Weight of fixed Shafts + Weight of Wiper mechanism + Weight of Miscellaneous parts

Total Weight = 1kg + 0.600Kg + 1.5Kg + 2 Kg

- Total Weight = 8.3 Kg

Initially, when we were designing our system, we neglected some factors such as how will the system move across the panel. To overcome this problem, we thought to utilize a chain-Sprocket mechanism. But the problem with such a system was that we could not incorporate flexibility meaning we could pick and place our system on another panel without overcoming a large amount of weight due to the rectangular frame, so we shifted towards a lightweight approach for the development of the hardware prototype.

3.3.2 Torque And Speed Of Motor

Mass m= 8.3 Kg

Assuming no energy loss occurs due to friction we can say that

Force = mass * acceleration

Since the weight is being displaced horizontally, so there will be friction between the Tyers so the force of friction is given by:

F_f= Coefficient u * Normal Force N

Normal Force N_f =w= mg

N_f=8.3Kg * 9.81 m/s^2

N_f=81.53 N

Since rolling friction between rubber and steel is u=0.002

Since we are using 4 rubber tyers to move the mechanism so

F_f = u *N

F_f = 0.002 * 81.53N

F_f = 0.16506 N

F_f = 4 * 0.16506 = .66025 N (due to usage of Four Tyers)

- Now the force that is required to move the weight.

F= m*a +F_f

F= 8.3 * a + 0.66025 N

Suppose the weight travels up to 3 m.

Distance d = v_i *t + 1/2*a8t^2

Assume that vi is zero at the initial starting position of the mechanism.

D=1/2*a*t^2

a=2*3m/t^2

if it takes about 5 sec to reach 3m

a=6m/5^2 sec^2

a=0.24 m/s^2

For the Torque of the Motor

Torque=F*r Suppose r=0.3 m

= (8.3 *.24 + 0.66025 N) * 0.3m

- Torque of Motor = 0.8 N.m

For Motor Speed,
Speed = Torque /moment of Inertia I *angular acceleration
I=0. 002Kg.m^2 (Motor Specification)
w=T/(I*alpha)
angular acceleration alpha = a / r
alpha = 0.24 m/s^2 /0.3m
alpha= 0.8 rad/s^2
speed w=0.8 N.m / (0.002 Kg/m^2 * 0.8 rad/s^2)

- speed of motor = 500 rpm

Rpm is divided into four motors that are fitted in motor mounts.

3.4 Software Simulation

In this section, we deal with the simulation work done for various electrical components such as the Motor driver, limit switches and water pump, etc.
The Simulation tool used for this purpose is Proteus 8.9 Professional which provides an integrated easy-to-use electronic design suite environment capable of handling small to large power electronic circuits. It provides a specific analysis of a circuit and gives an overview of how the circuit will behave in real-life scenarios.

3.4.1 Motor Driver Design

The purpose of this motor driver is to control the speed as well as the direction of the motor that is attached to the motor mount coupled with fixed shafts. The main idea behind a motor driver was to control the direction of four motors at the same time meaning that all motor should change their polarity at the same time frame.

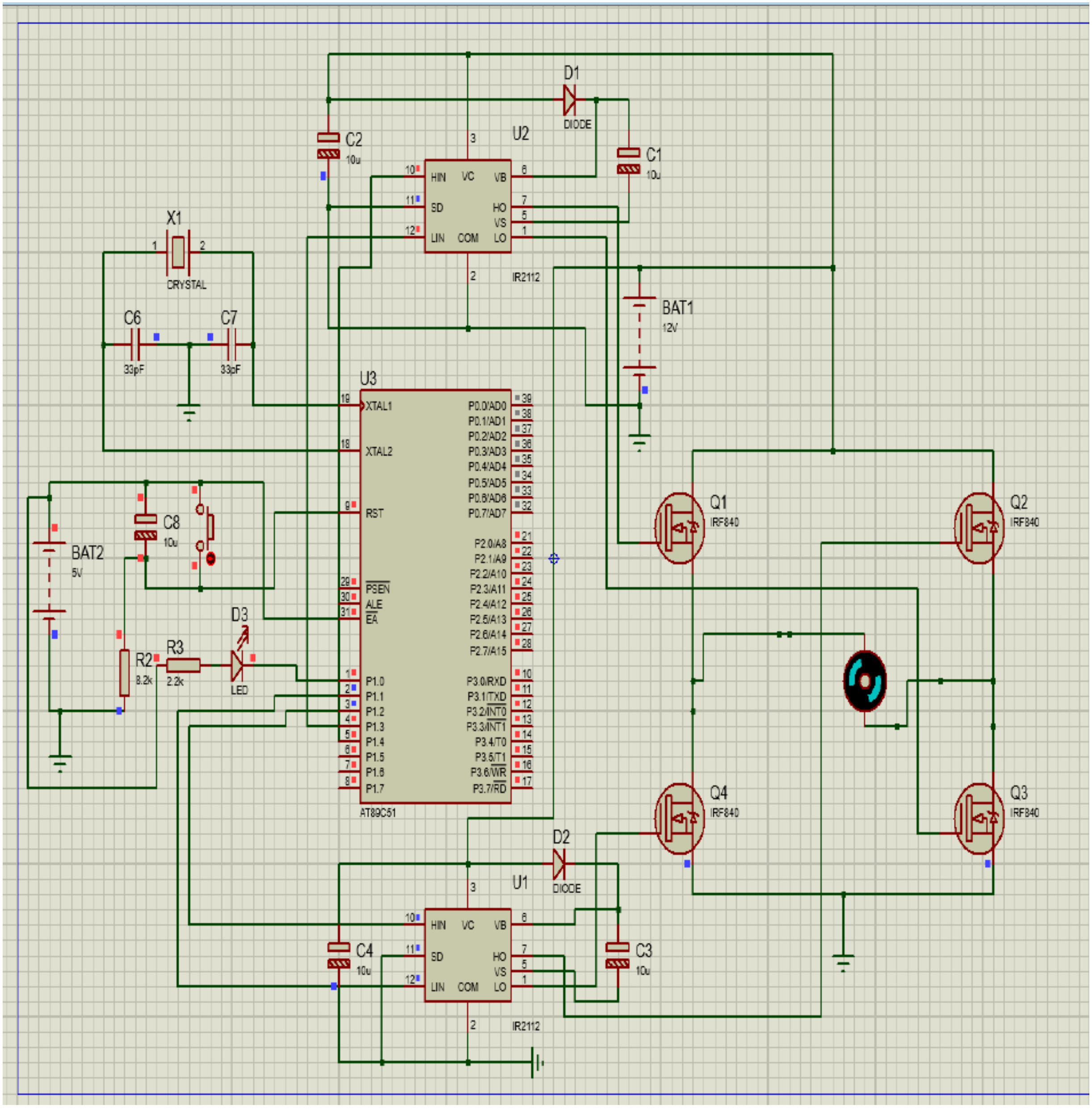


Figure 22 Motor Driver using AT89C51 and IRF840 MOSFET

The motor driver is designed using a h-bridge built using IRF 840 MOSFET whose switching is controlled IR2112 Voltage regulator. The IR2112 is controlled by the microcontroller AT89C51. The problem with building the motor driver from scratch was that all four motors would not change their direction at the same time causing the Moving mechanism to get stuck. To remove this problem, we opted for a relay-based switching of polarity so that all motors can synchronize with each other and switch their direction easily.

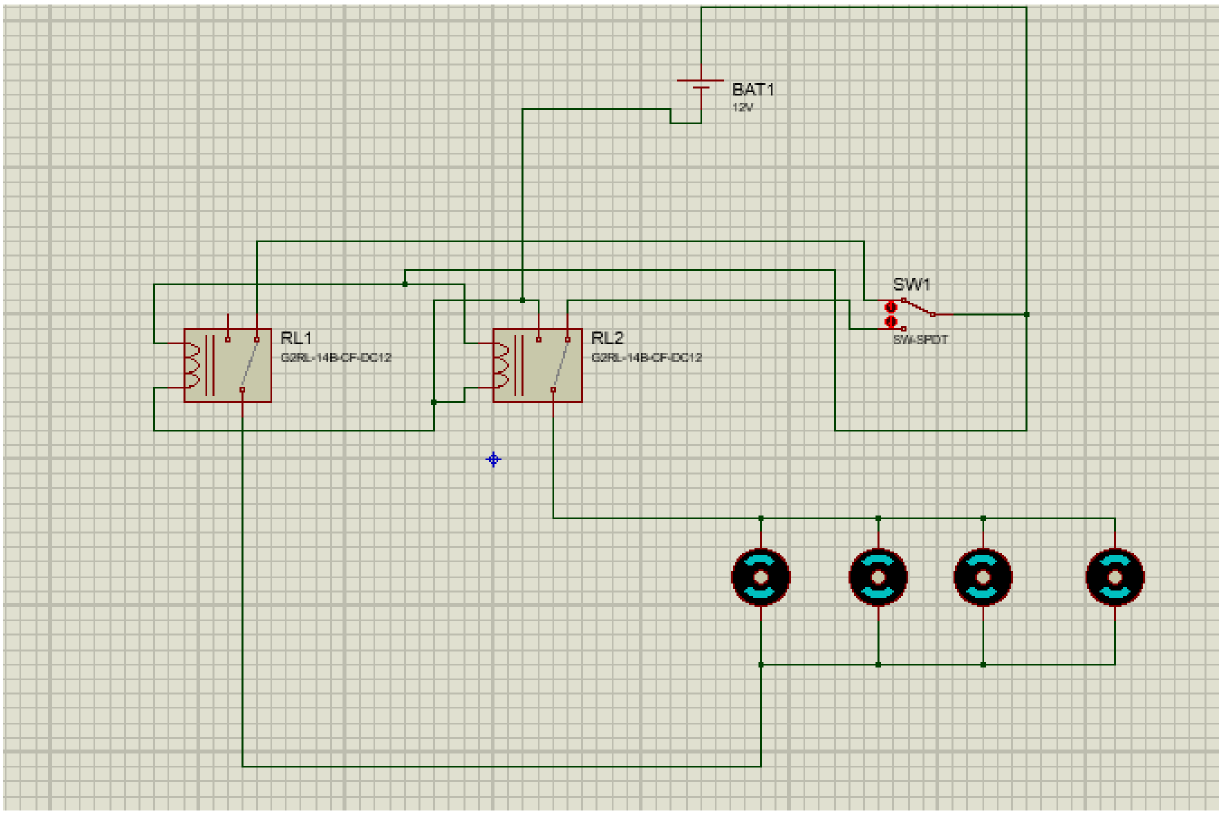


Figure 23 Relay-Based Motor Direction Change

3.4.2 Limit Switch

The limit was used in our system to detect and stop the moving mechanism at the start and end points of the solar panel. Limit switches work when external pressure is applied to the switch state, the moving mechanism moves across the panel and when external pressure is removed, the moving mechanism stops at either end of the solar panel.

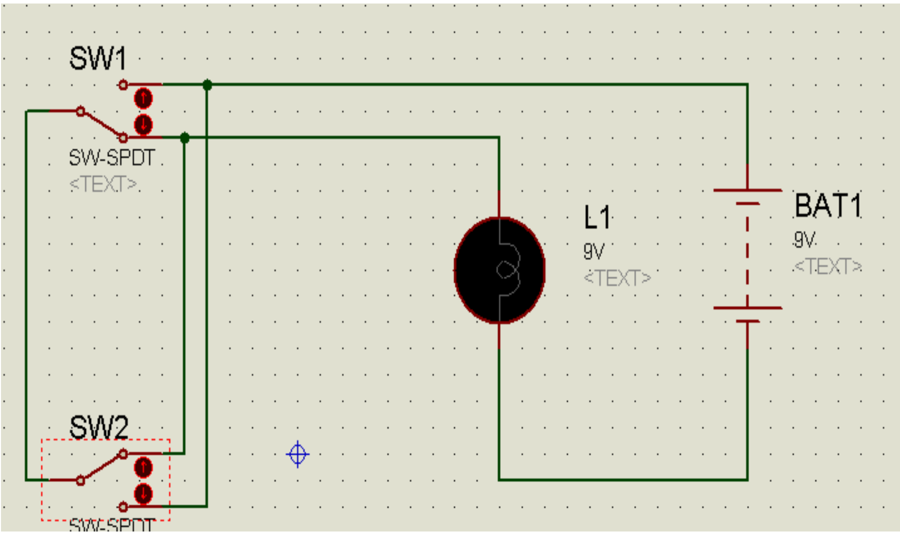


Figure 24 Proteus Symmetric for Limit Switch Using SPDT

sketch_feb23a.ino

```
#include <ezButton.h>

ezButton limitSwitch(7);  // create ezButton object that attach to pin 7;

void setup() {
  Serial.begin(9600);
  limitSwitch.setDebounceTime(50); // set debounce time to 50 milliseconds
}

void loop() {
  limitSwitch.loop(); // MUST call the loop() function first

  if(limitSwitch.isPressed())
    Serial.println("The limit switch: UNTOUCHED -> TOUCHED");

  if(limitSwitch.isReleased())
    Serial.println("The limit switch: TOUCHED -> UNTOUCHED");

  int state = limitSwitch.getState();
  if(state == HIGH)
    Serial.println("The limit switch: UNTOUCHED");
  else
    Serial.println("The limit switch: TOUCHED");
}
```

Figure 25 Arduino Code for Limit Switch

Figure 23 shows the working of a limit switch when controlled by a microcontroller such as Arduino Nano or ESP32 Wi-fi Module.

3.4.3 Pump Motor

A pump motor is used to suck water from the water tank and using a pipe mechanism, sprinkles the water on the solar panels. The Nylon brush and Wiper mechanism swipe all the extra grime from the panel surface achieving maximum cleaning accuracy.

Figure 24 Shows how the simulations of the Pump motor work and what type of component is used to create a controlled water pump.

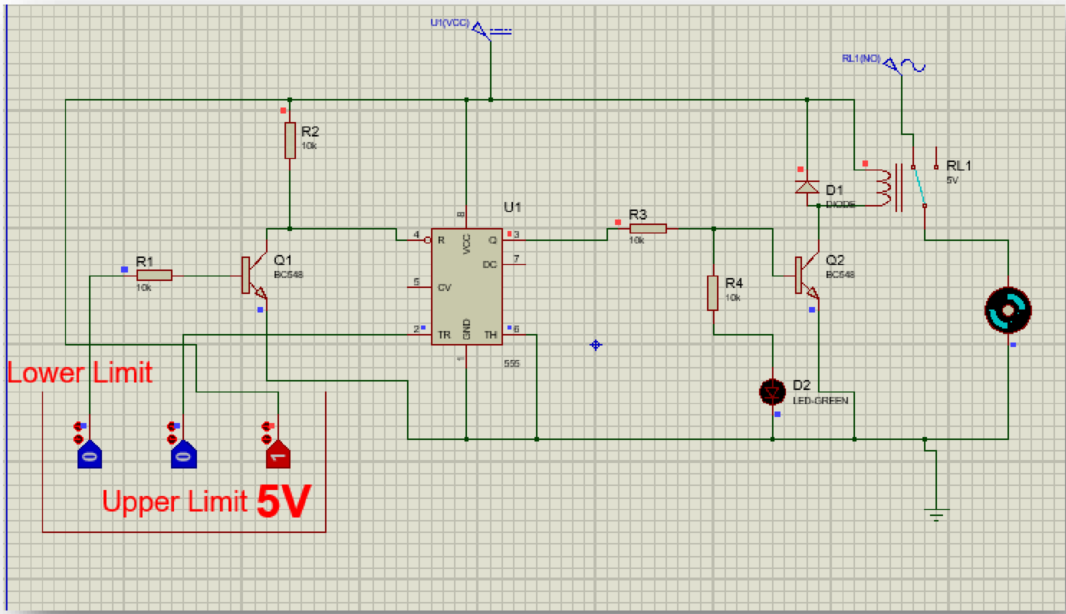


Figure 26 Pump Motor Proteus Simulation

3.4.4 Ultrasonic Sensor

This sensor was selected for the specific reason that depending upon the distance from the solar panel and between the solar panel edges we can control the moving mechanism for greater mobility for cross panel cleaning.

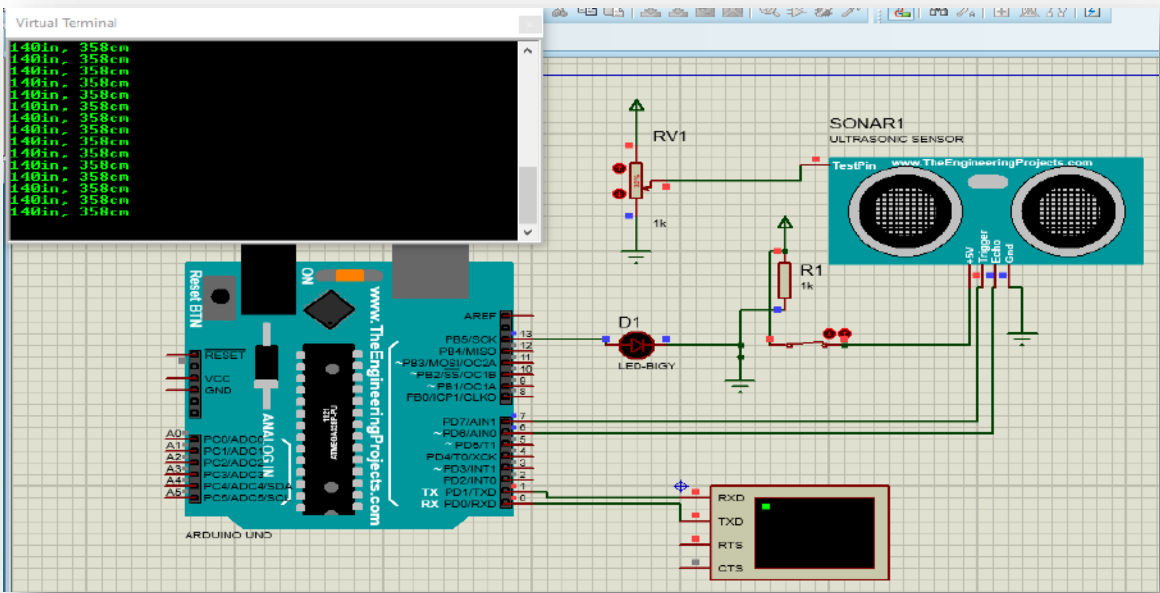


Figure 27 Ultrasonic Sensor Proteus simulation

3.5 Summary

In this chapter, the emphasis was on the design and simulation part of the project. We calculated the total weight of the Moving mechanism that will clean the solar panel surface. From the total weight of the system, we calculated the speed and torque of the motor. In the Software stage, we simulate different electrical components that can be used in our system to help mitigate control of the device.

Chapter 4

Hardware Development and Specification

Hardware development will include the Fabrication of different mechanical parts such as Motor mount, Solar frame structure, and Cleaning Mechanism. We also discussed the working of different electrical Components and how they are being used in our cleaning system.

4.1 System Specification

Overall system specifications are given in Table 2

Parameter	Max Value	Min value	Modality/Platform
Operating Voltage	14V	12V	Li-Po battery
Current	10A	7A	-
Torque (One Motor)	1.2 N.m	0.8N.m	Dc gear Motor
Mass	12 Kg	9 Kg	-
Power	140W	84W	Electrical Power
Communication	-	-	Wi-fi
Processor Speed (Main CPU)	2.4Ghz	-	32-bit Quad Core
Clock Speed (MHz)	8MHz	-	ESP 32

Table 2 System Specification Sheet

4.2 System Outline

The system outline gives an overview of the whole system and how it is interconnected with each other. Figure 26 shows the flow diagram of the system, how data is monitored and how the motor changes polarity due to the motor drives.

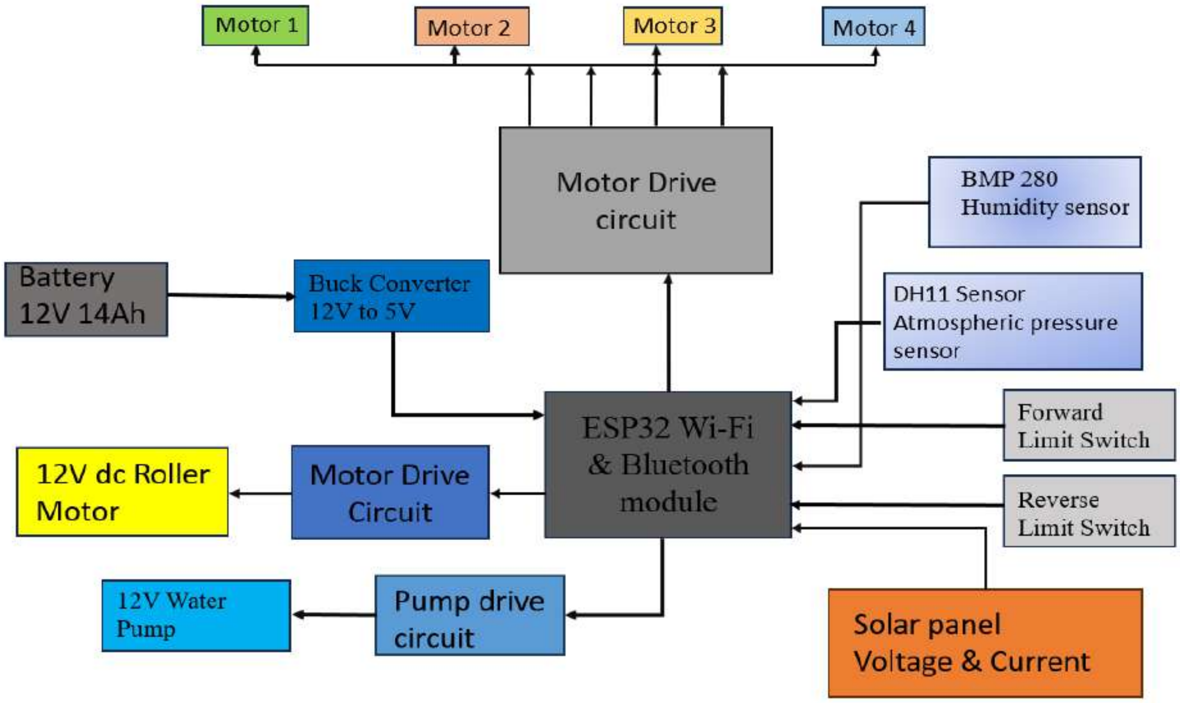


Figure 28 System Outline Flow Diagram

4.3 Component Explanation

4.3.1 ESP32 Wi-fi Module

ESP32 is a single 2.4 GHz Wi-Fi and Bluetooth combo chip designed with ultra-low-power 40 nm technology. ESP32 comes with 448 KB ROM and 520Kb SRAM. It also provides an internal 8MHz clock and an external clock capability of 2-60 MHz for Wi-fi and Bluetooth Functionality. The built-in microcontroller provides 34 programmable I/O's, 3 UART pins, and 1 data transmission channel. ESP32 has a wide variety of applications ranging from home automation, audio, health care, and wearable electronics.

4.3.1.1 ESP32 Usage

ESP32 is used to control the overall performance of the cleaning system. It helps to monitor sensory data and decide when to clean the solar panel. ESP32 Wi-fi module provides a gateway between the data and the cloud-based database.

Figure 29 ESP32 Wi-fi and Bluetooth Module[30]

4.3.2 DHT11 Humidity Sensor

It is a low-cost digital sensor for sensing temperature and humidity. This sensor can be easily interfaced with any microcontroller such as ESP32, Arduino, Raspberry Pi, etc. to measure humidity and temperature instantaneously. DHT11 is a relative humidity sensor. To measure the surrounding air, the sensor uses a thermistor and capacitive humidity sensor.

4.3.2.1 DHT11 Usage

The sensor is used to measure both temperature and humidity and data is transmitted via ESP32 to Real-time data monitoring (firebase server and Android app).

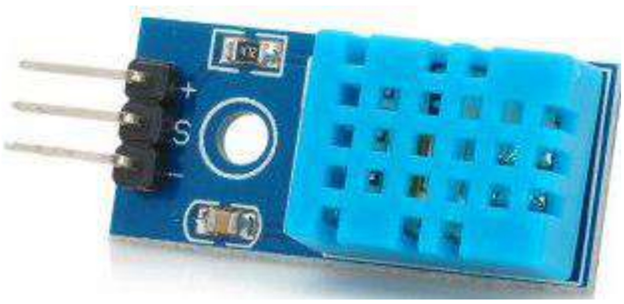


Figure 30 DHT11 Humidity & Temperature Sensor[31]

4.3.3 BMP 280 Atmospheric Pressure Sensor

The BMP 280 is an absolute barometric pressure sensor that provides high accuracy and linearity as well as long-term stability and high robustness. BMP 280 Sensor has applications in indoor & outdoor navigation, Weather forecast, etc. BMP 290 has an operation range of 300- 1100 hectopascal for pressure sensing and -40-85 degree Celsius for temperature sensing.

We are using the sensor for measuring both temperature and Atmospheric pressure in a real-time cloud-based data server.

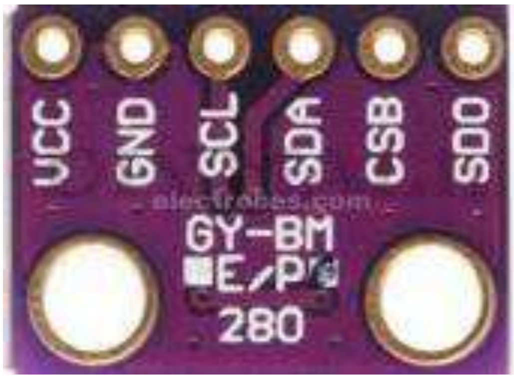


Figure 31 BMP 280 Temperature and Atmospheric Pressure Sensor[32]

4.3.4 LM2596 Buck Converter

LM2596 is a step-down switching regulator with all required active functions. It operates at 12 V and can provide an output voltage of 3.3 V, 5V, and is adjustable depending on the version you are using in the circuit. LM2596 can easily drive loads up to 3A with excellent line and load regulation. Applications of LM2596 Buck converter are in an area where there is a need for a high-efficiency Step-down regulator and positive-to-negative converter.

Our system utilizes the adjustable LM2596 by converting 12 V into 5V which is used for powering up ESP32 and other sensors.

Figure 32 LM2596 Buck Converter Adjustable[33]

4.3.5 Limit Switch

Limit switches are pressure-based mechanical actuators that are used for starting or stopping a particular task in a system. It can be used for controlling machinery as part of the control system, for safety purposes, and as a counter on conveyor belt type systems.

We use a limit in our system to start and stop the cleaning mechanism at either end of the solar plates.

Figure 33 Limit Switch

4.3.6 12V Relay

A combination of two 12V relays is used to change the polarity of the motor. This is done to operate all system motors in both reverse and forward modes.

Figure 34 12V Relay[34]

4.3.7 12V Water Pump

It is a 12V 1.5A operated water pump generally used for water coolers and in aquariums etc. We are using this pump to sprinkle water on the solar panel surface.

Figure 35 Water Pump 12V [35]

4.3.8 Battery Selection

- **At Full Load Condition:**
- ESP 32 Wi-Fi module

$I_{fL1} = 250mA$

- BMP 280 Humidity Sensor

$I_{fL2} = 0.001mA$

- DH II Atmospheric Pressure Sensor

$I_{fL3} = 3mA$

- Limit Switches

Since we are using 2 switches

$I_{fL4} = 2 \times 25mA = 50mA$

- Water Pump

5V operating Voltage; $I_{fL5} = 1.5A$

- 12V Dc Gear Motors with Helical rotor

$I_{fL6} = 1.2A \times 4 = 4.8A$

- 12V 3A Dc gear roller motor

$I_{fL7} = 3A$

Total Current= **9.55A≈10A**

So, we will select the battery of 12V 14AH.

Figure 36 12V 7Ah Battery

Since the maximum current is 14 Ah so we used two batteries of 7Ah in parallel to get the desired current output.

4.3.9 Solar Panel Parameters

To measure the panel voltage and current, we use direct current from the solar panel and pass it through a dc load to get Current Isc and voltage open circuit voc. For specification of solar panels refer to [36]

Figure 37 Solar Panel Current & Voltage Circuit

4.4 Hardware Prototype

The hardware prototype consists of Motor Mount, DC gear motors, a Frame structure for holding a Solar panel, and a cleaning mechanism fitted on the panel.

4.4.1 Motor Mount

They are fabricated through a laser engraving machine by using acrylic as a base material. The mount is made in such a way that it can hold two dc gear motors with them at each end of the solar cleaning mechanism. Figure 36 shows the fabricated model for the Motor mount top and side view.

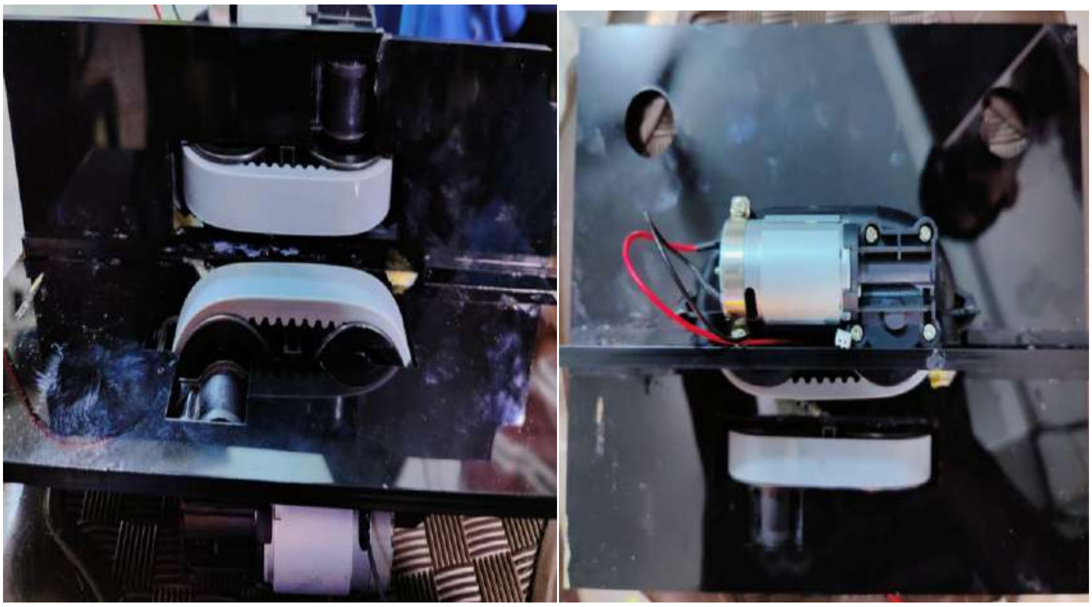


Figure 38 Motor Mount Side and Top View

4.4.2 Dc Gear Motor

The Dc gear motor that we used operates at 12V with a maximum full load current of 1.2A. The cleaning system used four motors of the same specification to control the movement of the cleaning mechanism in both forward and reverse directions. Figure 37 shows a different view of the Dc Gear Motor.

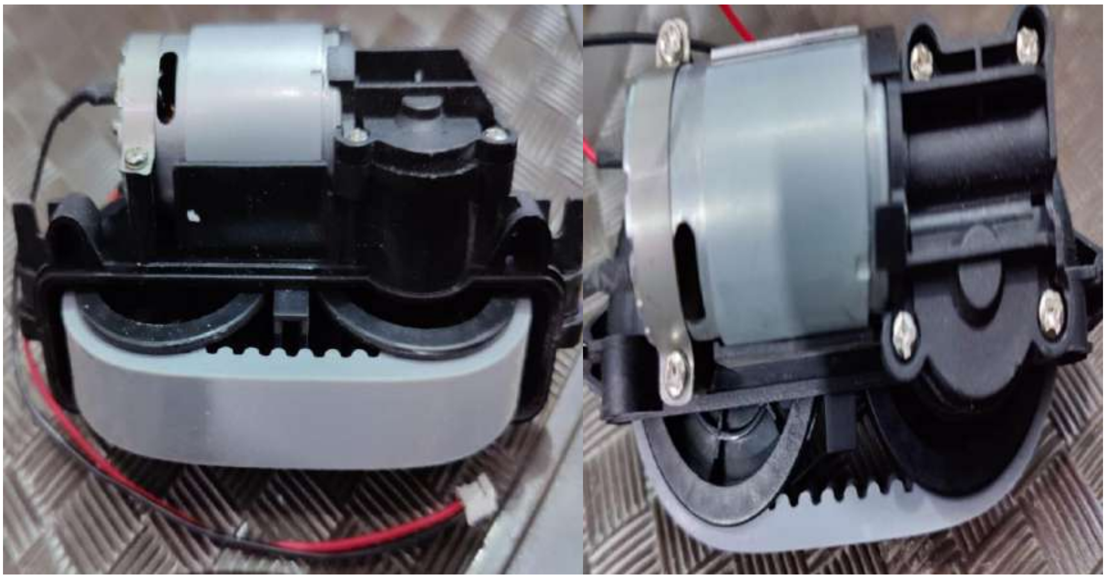


Figure 39 Different View of Dc Gear Motor

4.4.3 Rods Shaft With Frame Structure

Rod shafts are used to make a grip between the two motor mounts. The rods are fixed in place with the help of metal couplers. The solar panel is mounted on an iron frame structure which holds the panel in place at an angle of 26 degrees from the ground.

Figure 40 Shaft rod between Two Motor Mounts

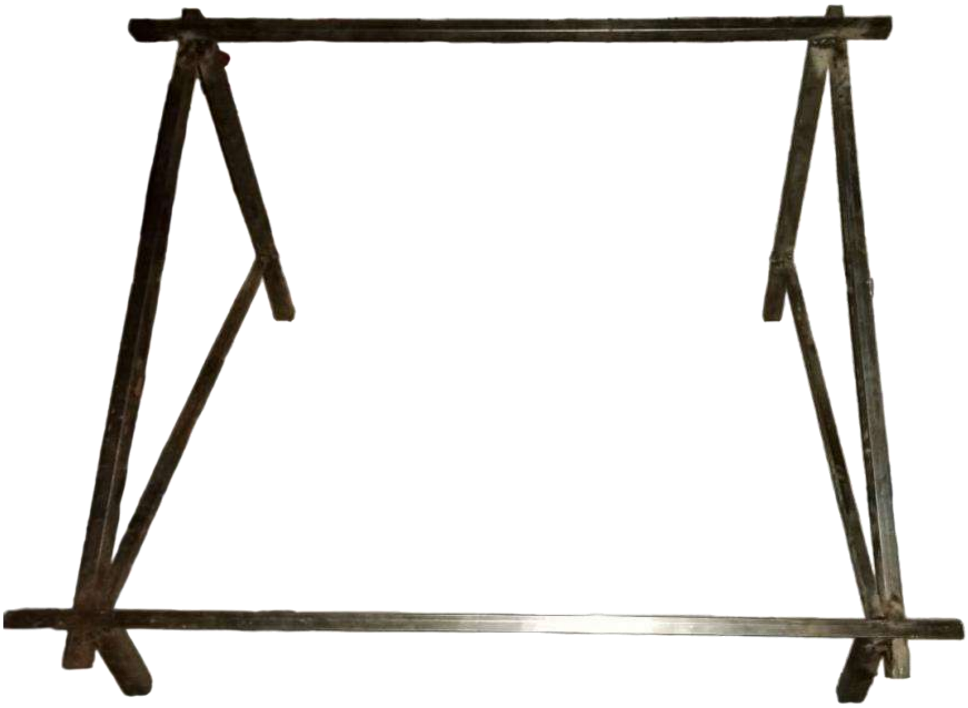


Figure 41 Solar Mounting Frame Structure

4.4.4 Working Prototype

The working prototype consists of a wiper, brush, and water-spraying mechanism attached to the fixed shafts. The fixed shafts are coupled with the motor mount at both ends of the solar panel. Water is pumped from the water tank that is attached to the solar frame structure on which the solar panel is placed at an angle of 26 degrees. The brush shaft is rotatable with the help of a 12V 3A Dc gear Motor. The wiper mechanism is freely mounted with the cleaning mechanism in such a way that it is automatically attached its rubbers to the panel surface. The data is monitored with the help of the ESP32 Wi-fi module which sends data to an online database server called Firebase. The decision when to clean the panel is based upon the sensory parameter such as solar panel voltage, current and environmental data such as humidity and Temperature, etc.

Figure 42 Working Prototype for Solar Panel Cleaning System

4.4.4.1 Firebase Real-Time Database

Firebase real-time database is a cloud-hosted database. Data is stored as JSON and Synchronized in Realtime to every connected client. On Firebase we have created an account named Solar panel cleaning System in which we monitor real-time solar panel and environmental factors such as humidity, temperature, and atmospheric pressure. Figure 42 shows how and where data is being monitored in real-time.

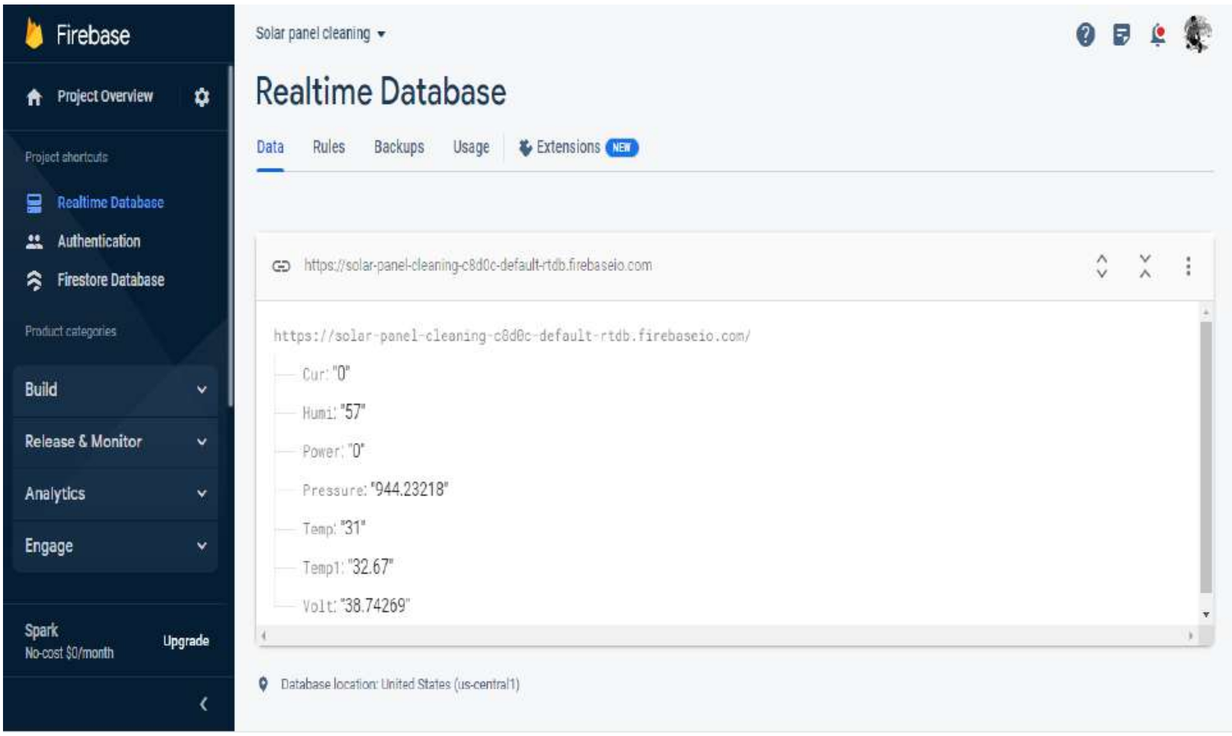


Figure 43 Real-time Database on Firebase Cloud Server

4.5 Summary

In this chapter, we covered the component we used and what are their benefits and usage. In industries and markets. How we used the component in our system to achieve reliability and sustainability in the environment. The chapter also covers how Fabricated hardware parts are made and used in the prototyping of the system. The next chapter will be based on the results achieved and testing of the prototype and how our results compared to other people's work.

Chapter 5

RESULT AND ANALYSIS

5.1 Code Explanation

The code given in Appendix A shows how data is being monitored and how the data is used to make the decision when to clean the solar panel.

```
for(int a=0;a<1000;a++)
{
 v+=analogRead(35);
 i+=analogRead(34);
 }
 v=v/52500.0;

 Serial.print("V: ");Serial.print(v);
 Serial.print("  I: ");Serial.println(i);
  Firebase.setString(fbdo,"Volt",v);
  Firebase.setString(fbdo,"Cur",i);
  Firebase.setString(fbdo,"Power", (v*i));

   DHT11();
       printValues();
     delay(1000);
```

Figure 44 Getting Data for Sensors

The solar panel data measuring circuit is connected to analog pins 34 and 35 of ESP32. The Analog read command converts the analog voltage and current data into digital values and sends them to the online cloud database. The data is compared with the assigned value to decide to clean the solar panel.

```
if((int)humidity>=55){
 Serial.println("run");
  digitalWrite(15,0);digitalWrite(2,1);  for(int a=0;a<=35;a++){delay(1000);}
  digitalWrite(15,1);digitalWrite(2,0);  for(int a=0;a<=35;a++){delay(1000);}

  }

  if(digitalRead(4)==0){
   Serial.print("Manual");

  digitalWrite(15,0);digitalWrite(2,1);  for(int a=0;a<=35;a++){delay(1000); Serial.print("Left");}
  digitalWrite(15,1);digitalWrite(2,0);  for(int a=0;a<=35;a++){delay(1000);Serial.print("Rite");}

   }
```

Figure 45 Code for Checking the data and making Cleaning Decision

After getting both environmental type and solar data we assigned a check for one of the parameters to decide the cleaning process. In the above screenshot, we assigned a humidity check for a specific value condition if the condition becomes true then the cleaning mechanism will start the cleaning process and once the mechanism reaches one end of the solar panel then it waits for some, and the motor moves the mechanism in the reverse direction.

5.2 Cleaning System Testing and Analysis

To test whether the system cleans effectively and analyze the accuracy of the cleaning system. Before starting the test, we need to create a situation by pouring dust and sand over the panel surface. We also need to check whether the system cleans the panel accurately with neatness and robustness.

Figure 46 Solar Panel with Dust and Sand particles

Figure 47 Solar panel after cleaning with Mechanism

5.2.1 Analysis Before Cleaning

It is observed that when the solar panel is not cleaned, the solar panel does not produce the maximum output current due to less absorption of sunlight. Before cleaning the solar panel, data shows that the main effect will be on the current which produces less energy as compared to when it is clean.

3.5.2 Analysis After cleaning

It is observed that after cleaning the solar panel, the power generated by the solar panel has seen a significant increase. The increase in power corresponds to an increase in the efficiency of the system. Since our solar panel is damaged the system may show irregularities in data. These are due to the breakage of solar panels.

5.3 Data Analysis

We are comparing different data from the sensors to decide on the best value for each parameter so the system may know at what instance should cleaning mechanism should be operated. Manual operation is also a viable solution if data is not being monitored or there is a crash in internet service.

5.3.1Humidity vs Temperature At daytime and Nighttime

The table below shows the comparison between humidity and temperature during the daytime Over a period of one month.

Humidity vs Temperature Sensor Data				
Dated	Temp during daytime (Deg C)	Temp during nighttime (deg C)	Humidity during Daytime	Humidity during nighttime
1-Jun-23	26	17	43	50
3-Jun-23	33	19	41	58
5-Jun-23	36	22	44	62
7-Jun-23	34	23	43	51
9-Jun-23	39	25	67	56
11-Jun-23	36	24	49	57
13-Jun-23	39	26	63	58
15-Jun-23	34	23	47	62
17-Jun-23	38	28	59	65
19-Jun-23	39	23	64	65
21-Jun-23	41	31	68	67
23-Jun-23	40	27	64	62
25-Jun-23	42	26	70	65
27-Jun-23	36	25	48	57
29-Jun-23	35	24	46	58

Table 3 Humidity Vs Temperature Dataset

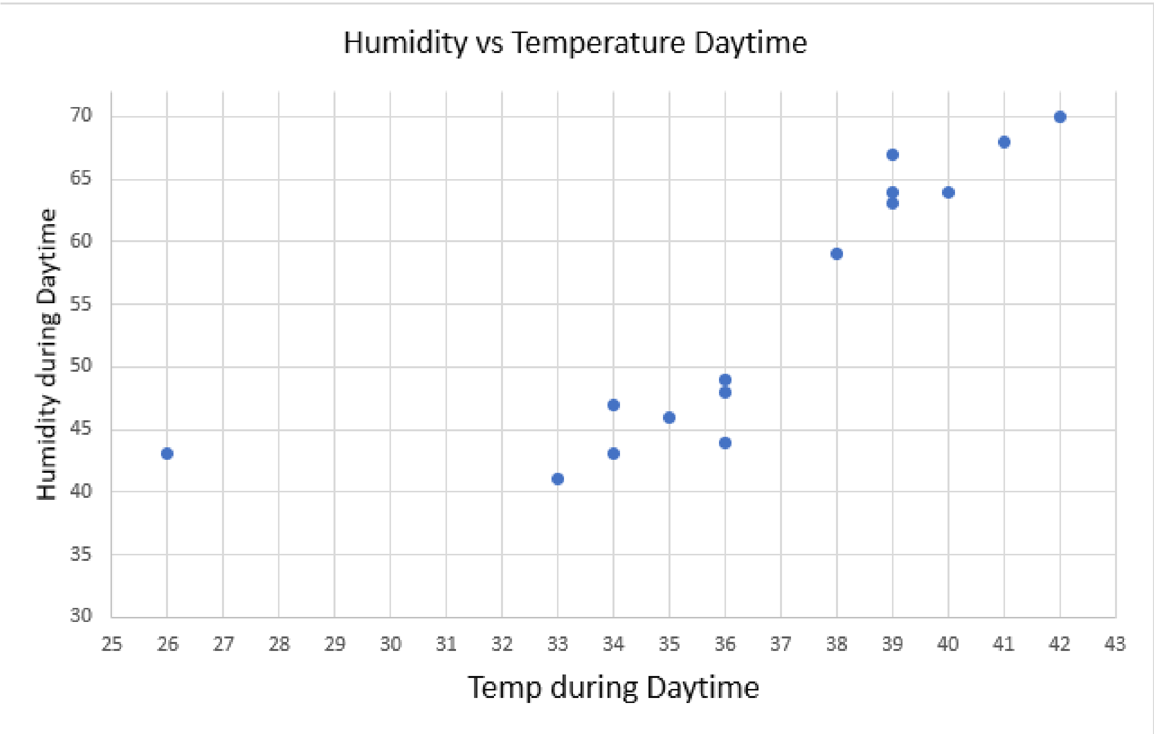


Figure 48 Graph Between Humidity Vs temperature at Daytime

Since it is summer season in June, due to high temperatures, humidity varies from 40 % to 70 % during the daytime.

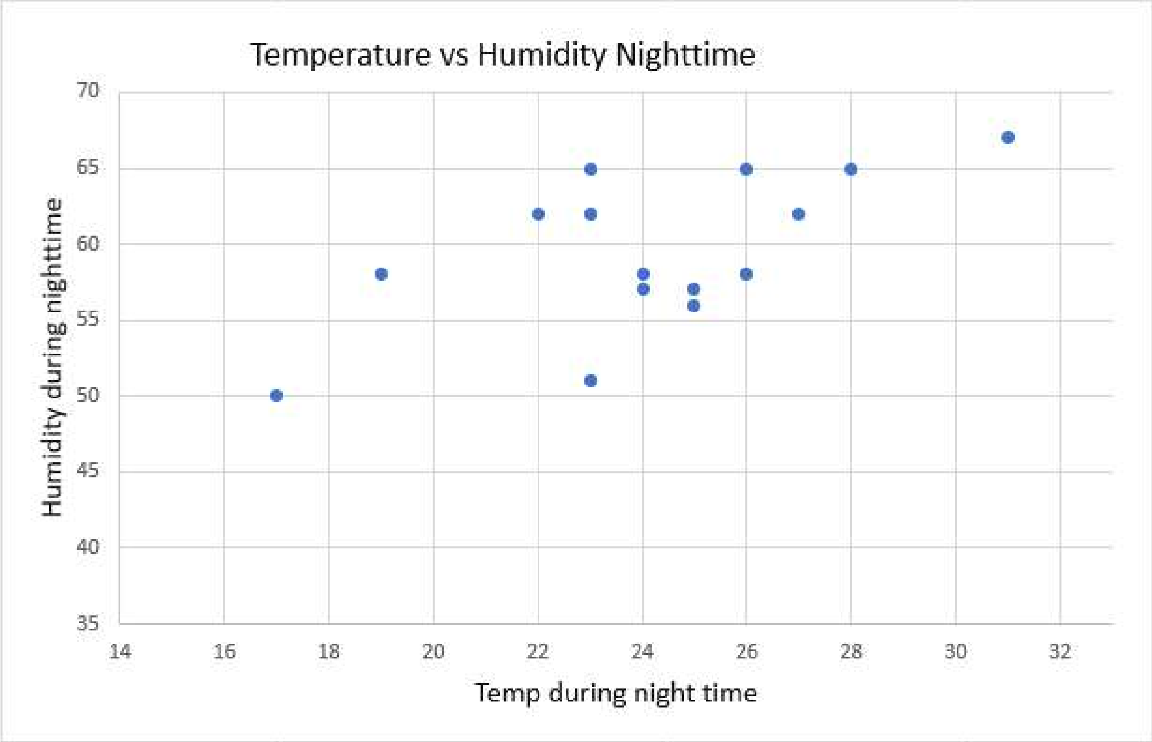


Figure 49 Temperatures vs Humidity during Nighttime

At nighttime due to temperature drops, the humidity stills vary from 40 to 60 percent so we can say that in normal temperatures day, we can tell our system to decide according to weather forecast data. It is a huge drawback that during the daytime and nighttime, there is no huge change in humidity content in the air. So other parameters can make decisions based on their data.

5.3.2 Voltage and Current Data Comparison

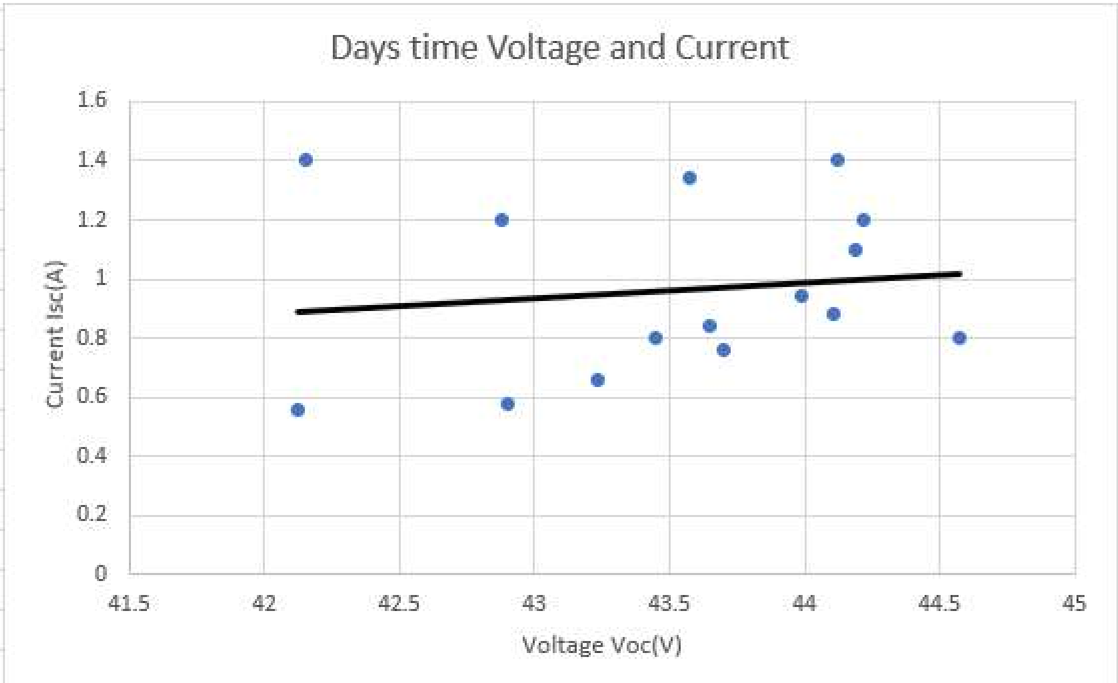


Figure 50 Voltage Vs Current During Daytime

From the graph, the solar panel voltage and current directly vary with each other. When the solar panel is not cleaned, the straight line will curve downward showing a decrease in power generation. The solar system will show the maximum power drops when it is in dusty conditions. Since the amount of dust varies from location to location, the voltage during peak sunlight will be high. At nighttime solar system goes on standby producing little to no power so voltage will also drop accordingly as shown in Figure 50.

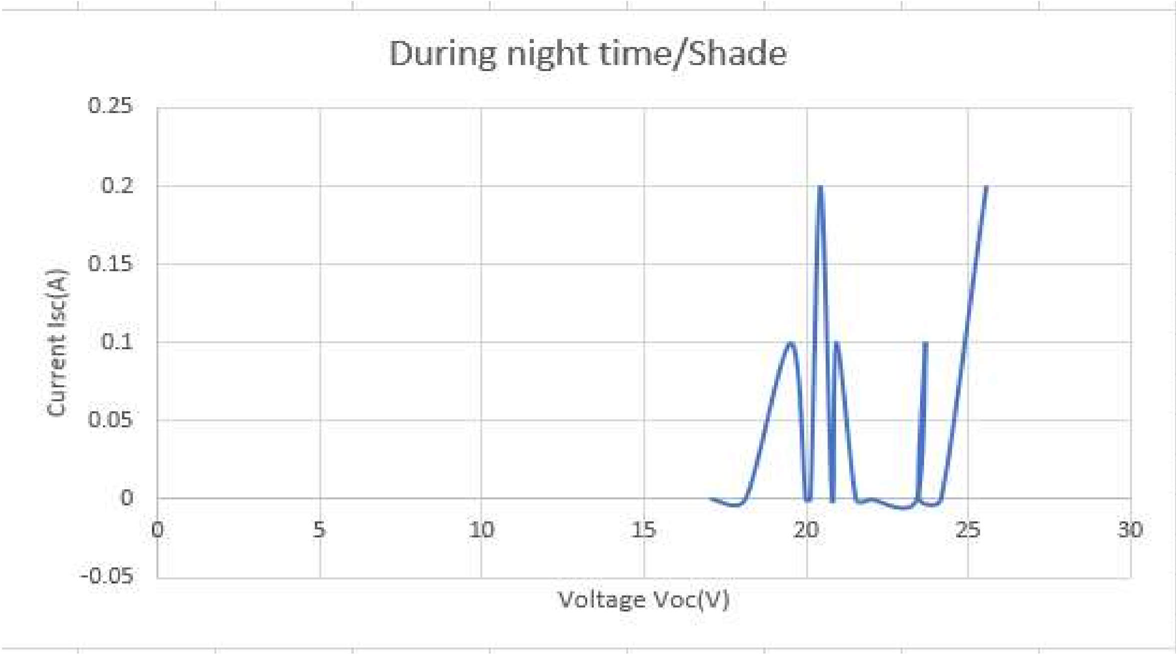


Figure 51 Voltage Vs Current during Nighttime

5.4 Summary

This chapter gives in-depth details of Arduino code written to control the cleaning mechanism and monitor sensory data in real-time database on cloud server called Firebase. The chapter analyses the data that we monitored during a single month. The section analyses the temperature vs Humidity and Voltage and Current at Daytime and Nighttime.

Chapter 6

CONCLUSION

Solar panel cleaning systems play a crucial role in ensuring the optimal performance and efficiency of solar panels. Regular maintenance and cleaning of solar panels can keep them free of dust, debris, dirt, and other atmospheric pollutants present in the air. The cleaner the panel, the more power will be generated by that panel.

The designed system provides more accurate cleaning of solar panels when water is used as a solvent but when the water pump is turned off, the cleaning mechanism is roughly wiping the dust towards the edges of the solar panels. To reduce such a drawback, we need a spongy type of rubber that can easily drag excess dust and dirt away from the panel surface when operating in forward mode.

The system designed will face water availability issues whenever the water tank reaches a dead level. The methodology applied to design the system is feasible if the system is automated and easy to move from panel to panel while cleaning.

The decision-making process is dependent upon real-time cloud-based database. The data value if they exceed a certain point then the cleaning mechanism will start its operations.

The result achieved during the testing phase of the cleaning mechanism shows that the system is working without interruptions and may need a tweak to the mechanical model to further improve cleaning accuracy and optimal speed.

6.1 Recommendations

The system designed has many discrepancies which need to be addressed in the future. Some Recommendations that future Engineers and Researchers must keep in mind while building such type of cleaning systems. Some of these recommendations are as followed:

1. Water availability is one of the major issues for water-based robotic systems so, design a system with less or no water usage.
2. Try to start the new project from scratch and design every part of the mechanical mechanism. It will give you better understanding of the working of Mechanical machinery.
3. Introduce new Sensor such as Light intensity, Irradiance Meter, and Power loss meters etc. to monitor solar system parameters for decision making process of the cleaning system.

4. The system that needs to be designed in the future must need to be cloudy and fully automated. The system designed has some limitations in its aspect of automation.
5. Apply new controlling technologies to have better system reliability and sustainability towards achieving maximum cleaning of dust, debris and dirt from the solar.

REFERENCES

[1] N. F. Zainuddin, M. N. Mohammed, S. Al-Zubaidi, and S. I. Khogali, "Design and Development of Smart Self-Cleaning Solar Panel System," *2019 IEEE Int. Conf. Autom. Control Intell. Syst. I2CACIS 2019 - Proc.*, no. June, pp. 40–43, 2019, doi: 10.1109/I2CACIS.2019.8825056.

[2] I. Naseem and J. Khan, "Impact of Energy Crisis on Economic Growth of Pakistan," *Int. J. African Asian Stud. J.*, vol. 7, pp. 33–43, 2015.

[3] H. Saulat, "Renewable energy resources current status and barriers in their adaptation for Pakistan Design and Construct Two-Dimensional Super Thin Materials View project wastewater treatment View project," no. January 2015, 2017, [Online]. Available: http://scienceq.org/Journals/JBCE.php

[4] and A. A. Bakhtiar, Farid, ""A review of solar energy in Pakistan: Current status and prospects.,"" *Sci. Technol. Dev.*, vol. 36.3 189–1, 2017.

[5] P. H. Shaikh, F. Shaikh, and M. Mirani, "Solar energy: Topographical asset for Pakistan," *Appl. Sol. Energy (English Transl. Geliotekhnika)*, vol. 49, no. 1, pp. 49–53, 2013, doi: 10.3103/S0003701X1301012X.

[6] S. R. Shakeel, J. Takala, and W. Shakeel, "Renewable energy sources in power generation in Pakistan," *Renew. Sustain. Energy Rev.*, vol. 64, pp. 421–434, 2016, doi: 10.1016/j.rser.2016.06.016.

[7] A. W. Bhutto, A. A. Bazmi, and G. Zahedi, "Greener energy: Issues and challenges for Pakistan-Solar energy prospective," *Renew. Sustain. Energy Rev.*, vol. 16, no. 5, pp. 2762–2780, 2012, doi: 10.1016/j.rser.2012.02.043.

[8] "No TitleHassan, M., Afridi, M. K., & Khan, M. I. (2018). An overview of alternative and renewable energy governance, barriers, and opportunities in Pakistan. Energy & Environment, 29(2), 184–203.", doi: doi. https://org/10.1177/0958305X17743036.

[9] "Trading into a Bright Energy Future," *Trading into a Bright Energy Futur.*, 2021, doi: 10.30875/b2e01618-en.

[10] "IRENA. Solar Energy—International Renewable Energy Agency. 2021.".

[11] R. J. Mustafa, M. R. Gomaa, M. Al-Dhaifallah, and H. Rezk, "Environmental impacts on the performance of solar photovoltaic systems," *Sustain.*, vol. 12, no. 2, pp. 1–17, 2020, doi: 10.3390/su12020608.

[12] A. A. S. A. El-gharabawy, "Review on Corrosion in Solar Panels," *Int. J. Smart grid,*

vol. 2, no. 4, pp. 3–5, 2018, doi: 10.20508/ijsmartgrid.v2i4.31.g29.

[13] R. Abdollahi, "Impact of wind on strength and deformation of solar photovoltaic modules," *Environ. Sci. Pollut. Res.*, vol. 28, no. 17, pp. 21589–21598, 2021, doi: 10.1007/s11356-020-12111-1.

[14] "Sreedath Panat Kripa K. Varanasi ,Electrostatic dust removal using adsorbed moisture–assisted charge induction for sustainable operation of solar panels.Sci. Adv.8,eabm0078(2022).DOI:10.1126/sciadv.abm0078".

[15] M. R. Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad, and S. Hajighorbani, "Power loss due to soiling on solar panel: A review," *Renew. Sustain. Energy Rev.*, vol. 59, pp. 1307–1316, 2016, doi: 10.1016/j.rser.2016.01.044.

[16] "M. R. Maghami, H. Hizam, C. Gomes, M. A. Radzi, M. I. Rezadad, and S. Hajighorbani, 'Power loss due to soiling on solar panel: A review,' Renewable and Sustainable Energy Reviews, vol. 59, pp. 1307-1316, 2016".

[17] Https://windowcleaningstuff.co.uk/shop-all/solar-panel-cleaning-kit-for-water-fed-systems/, "No Title".

[18] "X. Lu, Q. Zhang, and J. Hu, 'A linear piezoelectric actuator based solar panel cleaning system,' Energy, vol. 60, pp. 401-406, 2013.".

[19] "]P. Vasiljev, S. Borodinas, R. Bareikis, and A. Struckas, 'Ultrasonic system for solar panel cleaning,' Sensors and Actuators A: Physical, vol. 200, pp. 74-78, 2013.".

[20] "]J. Son et al., 'A practical superhydrophilic self cleaning and antireflective surface for outdoor photovoltaic applications,' Solar Energy Materials and Solar Cells, vol. 98, pp. 46-51, 2012".

[21] "G. He, C. Zhou, and Z. Li, 'Review of self-cleaning method for solar cell array,' Procedia Engineering, vol. 16, pp. 640-645, 2011.".

[22] "N. Khadka, A. Bista, B. Adhikari, A. Shrestha, and D. Bista, 'Smart solar photovoltaic panel cleaning system,' IOP Conference Series: Earth and Environmental Science, vol. 463, no. 012121, 2020".

[23] "https://serbot.ch/en/solar-panels-cleaning/gekko-solar-robot".

[24] "Solar Brush. Available: https://www.aerialpower.com/solarbrush/".

[25] "(2020, April 15). Intellegent cleaning robots. Available: https://bosonrobotics.com/en/products/robot".

[26] M. R. Habib *et al.*, "Automatic Solar Panel Cleaning System Based on Arduino for Dust Removal," *Proc. - Int. Conf. Artif. Intell. Smart Syst. ICAIS 2021*, pp. 1555–

1558, 2021, doi: 10.1109/ICAIS50930.2021.9395937.

[27] S. P. Aly, P. Gandhidasan, N. Barth, and S. Ahzi, "Novel dry cleaning machine for photovoltaic and solar panels," *Proc. 2015 IEEE Int. Renew. Sustain. Energy Conf. IRSEC 2015*, 2016, doi: 10.1109/IRSEC.2015.7455112.

[28] N. Ronnaronglit and N. Maneerat, "A cleaning robot for solar panels," *Proceeding - 5th Int. Conf. Eng. Appl. Sci. Technol. ICEAST 2019*, pp. 1–4, 2019, doi: 10.1109/ICEAST.2019.8802521.

[29] N. Khadka, A. Bista, B. Adhikari, A. Shrestha, and D. Bista, "Smart solar photovoltaic panel cleaning system," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 463, no. 1, 2020, doi: 10.1088/1755-1315/463/1/012121.

[30] "ESP32."

[31] "DHT11."

[32] "https://www.bosch-sensortec.com/products/environmental-sensors/pressure-sensors/bmp280/".

[33] "LM2596."

[34] W. Y. W. Com, "5Volt Relay datasheet," pp. 4–5.

[35] "https://www.daraz.pk/products/dc-12v-water-pump-for-air-cooler-shafi-12-volt-water-pump-12-volt-dc-water-pump-12v-dc-water-pump-i300505446.html".

[36] L. Jinko Solar Co., "Tiger Pro 72HC 550 Watt MONO-FACIAL MODULE," pp. 3–4, 2020, [Online]. Available: www.jinkosolar.com

APPENDICES

APPENDIX A

CODE

```
#include <SimpleDHT.h>
int pinDHT11 = 19;
#include <Wire.h>
#include <Adafruit_Sensor.h>
#include <Adafruit_BMP280.h>
SimpleDHT11 dht11(pinDHT11);
#define SEALEVELPRESSURE_HPA (1013.25)
Adafruit_BMP280 bmp; // I2C
//Adafruit_BME280 bme(BME_CS); // hardware SPI
//Adafruit_BME280 bme(BME_CS, BME_MOSI, BME_MISO, BME_SCK); // software SPI
unsigned long delay time;
#include <WiFi.h>
#include <FirebaseESP32.h>
#include "WiFi.h"
#define WIFI_SSID "project1"
#define WIFI_PASSWORD "11223344"
#define FIREBASE_HOST "https://solar-panel-cleaning-c8d0c-default-rtdb.firebaseio.com"
#define FIREBASE_AUTH "QVecb3HgQwLomoOioO0aHTaAGdogNrPeng2ws8Jz"
FirebaseData fbdo;
FirebaseData getdata1;
float v=0;
float i=0;
byte temperature = 0;
byte humidity = 0;
void setup() {
 Serial.begin(115200);
pinMode(15,OUTPUT);
pinMode(2,OUTPUT);
pinMode(4,INPUT_PULLUP);
digitalWrite(15,1);digitalWrite(2,0);
 Serial.println("Satart");
 WiFi.begin(WIFI_SSID, WIFI_PASSWORD);
 Serial.print("Connecting to Wi-Fi");
 while (WiFi.status() != WL_CONNECTED)
 {
```

```
    Serial.print(".");
    delay(300);
  }
  Serial.println();
  Serial.print("Connected with IP: ");
  Serial.println(WiFi.localIP());
  Serial.println();
  Firebase.begin(FIREBASE_HOST, FIREBASE_AUTH);
  Firebase.reconnectWiFi(true);
   Serial.println(F("BME280 test"));
  bool status;
  // default settings
  // (you can also pass in a Wire library object like &Wire2)
  status = bmp.begin(0x76);
  if (!status) {
    Serial.println("Could not find a valid BME280 sensor, check wiring!");
   // while (1);
  }
  Serial.println("-- Default Test --");
  delayTime = 1000;
  Serial.println();
}
void loop() {
v=0;
i=0;
for(int a=0;a<1000;a++)
{
 v+=analogRead(35);
 i+=analogRead(34);
 }
 v=v/52500.0;
 Serial.print("V:");Serial.print(v);
 Serial.print(" I:");Serial.println(i);
  Firebase.setString(fbdo,"Volt",v);
  Firebase.setString(fbdo,"Cur",i);
  Firebase.setString(fbdo,"Power",(v*i));
   DHT11();
      printValues();
     delay(1000);
 if((int)humidity>=55){
  Serial.println("run");
    digitalWrite(15,0);digitalWrite(2,1);   for(int a=0;a<=35;a++){delay(1000);}
    digitalWrite(15,1);digitalWrite(2,0);   for(int a=0;a<=35;a++){delay(1000);}
```

```
    }

    if(digitalRead(4)==0){
      Serial.print("Manual");

    digitalWrite(15,0);digitalWrite(2,1);        for(int    a=0;a<=35;a++){delay(1000);
Serial.print("Left");}
    digitalWrite(15,1);digitalWrite(2,0);                                  for(int
a=0;a<=35;a++){delay(1000);Serial.print("Rite");}
     }
  }
  void DHT11(void) {
   // start working...
   Serial.println("=================================");
   Serial.println("Sample DHT11...");
   // read without samples.
   int err = SimpleDHTErrSuccess;
   if ((err = dht11.read(&temperature, &humidity, NULL)) != SimpleDHTErrSuccess)
{
    Serial.print("Read DHT11 failed, err="); Serial.print(SimpleDHTErrCode(err));
    Serial.print(","); Serial.println(SimpleDHTErrDuration(err)); delay(1000);
    return;
   }
   Serial.print("Sample OK: ");
   Serial.print((int)temperature); Serial.print(" *C, ");
   Serial.print((int)humidity); Serial.println(" H");
   Firebase.setString(fbdo,"Temp",temperature);
   Firebase.setString(fbdo,"Humi",humidity);
   // DHT11 sampling rate is 1HZ.
  }
  void printValues() {
   Serial.print("Temperature = ");
   Serial.print(bmp.readTemperature());
   Serial.println(" *C");

   // Convert temperature to Fahrenheit
   /*Serial.print("Temperature = ");
   Serial. Print(1.8 * bme.readTemperature() + 32);
   Serial.println(" *F");*/
   Serial.print("Pressure = ");
   Serial.print(bmp.readPressure() / 100.0F);
   Serial.println(" hPa");
   Serial.print("Approx. Altitude = ");
   Serial.print(bmp.readAltitude(SEALEVELPRESSURE_HPA));
```

```
  Serial.println(" m");
    Firebase.setString(fbdo,"Temp1",bmp.readTemperature());
  Firebase.setString(fbdo,"Pressure",bmp.readPressure() / 100.0F);
//  Serial.print("Humidity = ");
//  Serial.print(bmp.readHumidity());
//  Serial.println(" %");
  Serial.println();
}
```