DESIGN AND DEVELOPMENT OF AUTOMATIC SOLAR PANEL CLEANING MECHANISM

A

REPORT

SUBMITTED IN PARTIAL FULFILLMENT OF THE MINOR PROJECT –II (4ME33) COURSE

For the award of

Bachelor of Technology

(Mechanical Engineering)

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Vallabh Vidyanagar - 388 120

Affiliated to Gujarat Technological University

May 2023

CERTIFICATE

Date: 02/05/2023

This is to certify that the Minor Project II (4ME32) entitled "**DESIGN & DEVELOPMENT OF AUTOMATIC SOLAR PANEL CLEANING MECHANISM**" has been carried out by Parthkumar Sohaliya, Milan Ramani, Aditya Jamkar, Bhargav Patel the 8th semester under my guidance in partial fulfillment of the degree of Bachelor of Technology in Mechanical Engineering, Birla Vishvakarma Mahavidylaya, Vallabh Vidyanagar, during the academic year 2022-23.

09/05/2023

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Originality Report Certificate

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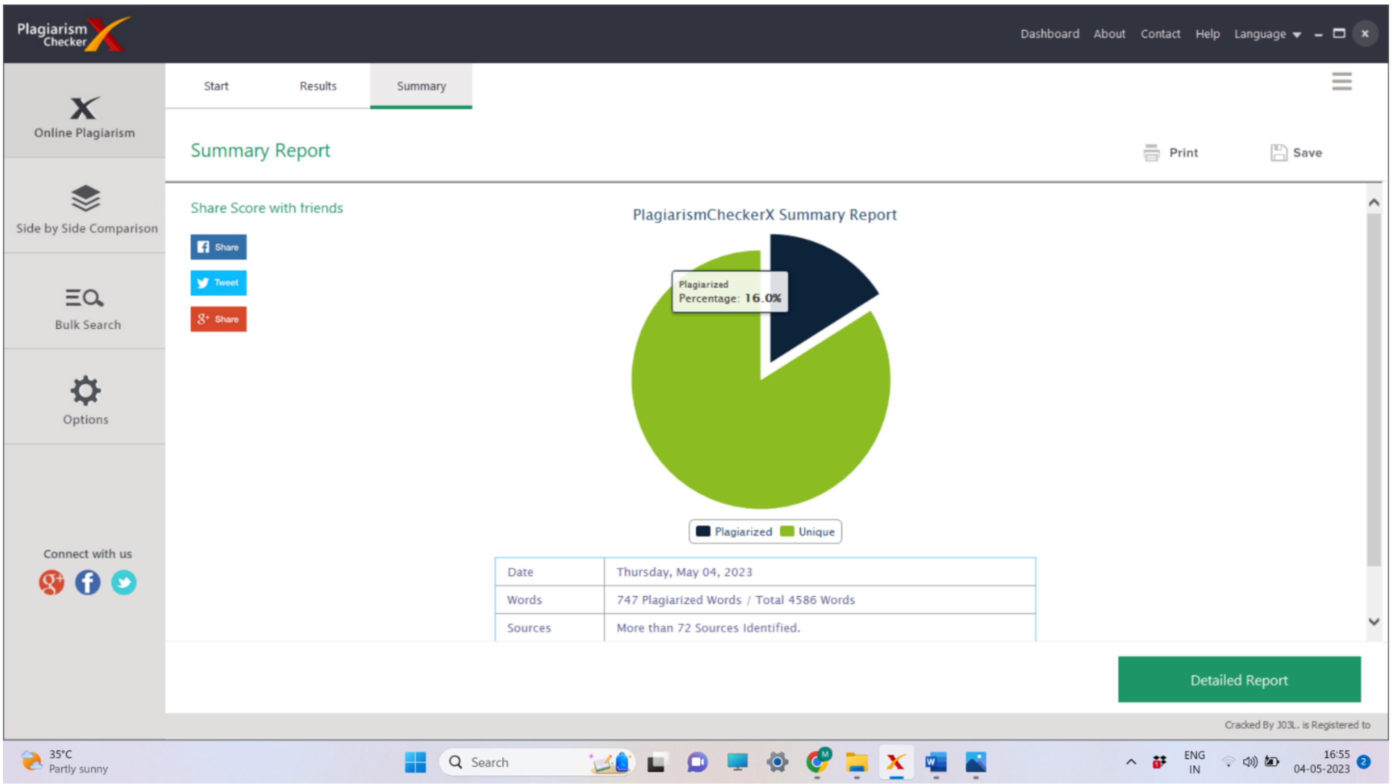

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Acknowledgement

We are grateful to Dr. Hitesh Bhargav of the Mechanical Engineering Department at Birla Vishvakarma Mahavidyalaya in V. V. Nagar for his advice during the entirety of our project and for sharing his vast expertise in the field of renewable energy. Throughout this semester, we appreciate his inspiration, support, and encouragement. Our project would not have been possible without his wide-ranging expertise and meticulous attention to every aspect of it.

I would also grateful my heartfelt appreciation to Lab Assistant Khatri Bhai for his excellent assistance, dedication, and patience in helping me with my experiments and lab work. His expertise and guidance were instrumental in the success of my research project.

We would like to express our gratitude to our friends for their ongoing support with our initiative. It gives me great pleasure to take this chance to thank all the people who have supported our mission and education. We apologise if we left someone out.

Abstract

An autonomous solar panel cleaning system is the focus of the project's design and development. The major goal of this design prototype is to clean the solar panel utilising an electrical mechanism with artificial intelligence so that the quality or efficiency of the solar panel is not diminished. Actually, because to the numerous dust storms that the desert region experiences, it is necessary to regularly clean the solar panels. It will be incredibly expensive and time consuming to complete the operation manually. In modern times, solar photovoltaic systems are widely used in both commercial and residential contexts. It has been reported that due to accumulations of dust, bird droppings, snow, and salt along the coast, among other things, the majority of photovoltaic systems perform poorly. Solar PV system problems have been addressed using a wide range of different technologies. The best method of dust removal for a solar cell is a solar panel cleaning system that cleans automatically, using both dry and wet cleaning.

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1.1 Introduction

1.1.1 Global Energy Requirements

The need for energy on a global scale has grown dramatically over the last few decades, and by 2030, it is expected to have climbed by more than 50%. The majority of the world's energy needs are currently being satisfied by traditional energy sources like coal, gas, and oil, but these resources are being utilised in an unrestrained way that will soon deplete all remaining fossil fuel supplies. Solar power is increasingly being used due to growing electricity prices and concerns about the environmental effects of fossil fuels.

1.1.2 Renewable Energy

In India, the field of renewable energy is still in its infancy. India established the world's first ministry of unconventional energy sources in the early 1980s. Its success has been sporadic, though. India has recently lagged behind other countries in the utilisation of renewable energy (RE). Less than 1% of India's overall energy requirements come from renewable energy. The Ministry of New and Renewable Energy in India is in charge of overseeing renewable energy.

1.1.3 Solar Energy

solar energy India is well-suited for using solar energy due to its high sun insolation and dense population. One of the initial uses of solar energy was to start replacing India's four to five million diesel-powered water pumps, each utilising around 3.5 kilowatts, and off-grid lighting because a large portion of the country lacks an electrical grid. A 35,000 km2 area of the Thar Desert has been designated for solar power projects, with the capacity to produce 700 to 2,100 gigawatts. A number of significant projects have been proposed.

In recognition of its contributions to the creation of a consumer financing programme for solar household power systems, the Indian Solar Loan Programme, which is backed by the United Nations Environment Programme, has been honoured with the prestigious Energy Globe World award for Sustainability. More than 16,000 solar household systems have been financed over the course of three years through 2,000 bank branches, primarily in rural South Indian regions where the energy grid is still underdeveloped.

The Jawaharlal Nehru National Solar Mission was proposed by the Indian government in November 2009 as part of the National Action Plan on Climate Change, with goals to generate 1,000 MW of power by 2013 and up to 20,000 MW of grid-based solar power, 2,000 MW of off-grid solar power, and cover 20 million sq metres with collectors by the mission's end in 2020.

1.1.4 Salient Features and Benefits of solar System

- A clean, silent and eco-friendly source of power
- Solar modules convert sunlight into electricity without pollution
- Negligible maintenance as there are no moving parts and maximum reliability
- Long life span of solar modules
- Modular design and easily expandable
- Simple installation: can be mounted on roof top or ground
- Can be installed at point-of use to avoid transmission losses
- Energy Independence
- Protection against future escalation of energy costs
- Available throughout the year

1.1.5 Impurities on solar panel

The frequent cause of poor system performance is build-up of dirt, dust, and mould, which can often limit power output by 10% to 15%. If enough bird droppings accumulate on one or more panels to partially cover one or more solar cells, a reverse current will result, which will have a higher impact and even result in hot spots.

The production from the solar panels is continually decreased as a result of dust accumulation on the panels. Dust accumulations on the top surface of solar panels limit solar flux and lower irradiance reaching the solar cell, which causes power loss. According to the literature, these problems can result in losses of up to 15% of the daily generation capacity.

Mold and lichen growth, especially in colder areas, can also drastically lower performance if the lichen covers a piece of one of the cells, causing reverse current. Potential consequences include the development of hot spots and irreversible cell damage. Use water and a brush to get rid of any lichen or mould growth.

1.1.6 Solar Cleaning

Instead of using soap, which leaves a residue that not only shadows panels but also attracts dirt, Solar Cleaning has discovered that utilising deionized water with a rolling or vehicle-mounted brush makes it possible to clean panels.

Cleaning frequency can be decided on the basis of in which environment solar panel is located & which type of impurities have more chances of accumulations.

1.2 Objective Statements

- Design a solar panel cleaning system which can increase the efficiency of solar panels.
- 2. Increase the power production of solar panels.
- 3. design & development of simple and automated cleaning mechanism for solar panels.
- 4. Minimize human intervention.
- 5. A cleaning system that does not affect the quality of the original solar panel.
- 6. An environmentally friendly cleaning system.

1.3 Project Specifications

- The solar panel cleaning system operates automatically.
- Increase the efficiency at least by 10%.
- Reduce the use of cleaning water.
- An autonomous mechanism brush to clean the 50 W solar panel

1.4 Project Application

The system is best suited for businesses and organisations whose energy consumption is highest during the hours of daylight. Manufacturing firms, software development centres, hotels, hospitals, schools, colleges, fuel pump stations, R&D centres, transmission towers, railways, and communication towers are just a few examples of these.

1.5 Methodology

- Find the research gap through literature survey
- Identify the requirement of cleaning mechanism for household application
- Design of the system
- Fabrication of system
- Experimentation and optimization of system
- Incorporate of AI for automation
- Results and discussion

Chapter **2**

Literature Review

There are several mechanisms for cleaning of solar PV system are discussed in literature among which five efficient technologies are discussed herewith.

2.1 Solar PV Cleaning Methods

1. **Robotic Mechanism**
2. **Piezoelectric**
3. **Coating**
4. **Wet and Dry Cleaning**
5. **Electrostatic Repulsion**

2.1.1 Robotic Mechanism

Khadka et.al investigated about the solar farm site which is very far to reach involving high transportation costs, or if the site is subjected to the frequent sand storm, it is suggested to implement a robotic cleaning mechanism. Multiple numbers of the robotic unit need to be placed on each of the arrays and an autonomous unit is placed to sense the real-time condition of the site. The autonomous unit is considered as the master unit and commands robotic units to clean their respective array; else looking upon the condition of the plant, operators themselves can command robotic units remotely. In this research an Internet of Things based model naming Smart Solar Photovoltaic Cleaning System is presented, mainly focusing its implementation on a large-scale solar plant with standard panel configuration.[20]

On January 27, 2021, in Coimbatore, India, Yerramsetty et al. conducted an experiment using the Automatic Robot to design and implement a floating solar panel cleaning system using AI technique. Using internet communication, the robotic car acts in this method as a manually operated vehicle. Gear motors drive the robot, and motor has a cleaning brush attached to it for motorised cleaning. It will work rapidly to clean the panel. Robotic camera-equipped monitor that can be manually operated using a smartphone and Node Red. It is connected to the Wi-Fi. More energy is utilised in this system, therefore more water is required.[28]

Figure 1. Image of Robotic [1.1]

Akhtar et al. constructed a system that cleans the solar panel surface with using Dry cleaning with nylon brush and with ARDUINO Mega controller. They utilised a cleaning robot in this mechanism, which moved around the solar panel's borders with the use of nylon wheels that were specially made for the purpose. These wheels are powered by 12-volt, high-torque motor is used to activate the roller brush. As a result, they discovered that frequent cleaning at predetermined intervals boosted system efficiency by 80 to 90 percent. Only dust particles could be cleaned by this technology. Since they did not utilize water in this experiment, they were unable to remove the bird droppings.[1]

2.1.2 Piezoelectric

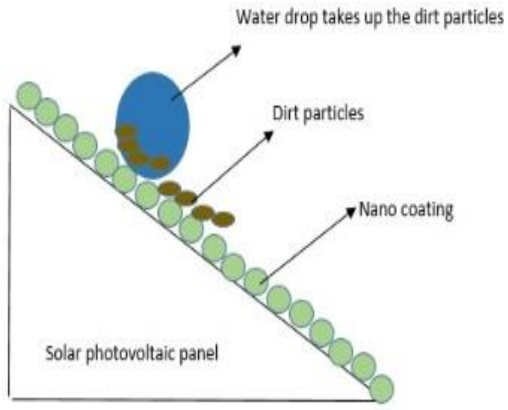


Figure 2. Image of Piezoelectric

Nasib Khadka et al. investigated Current Practices of Solar Photovoltaic Panel Cleaning System and Future Prospects of Machine Learning Implementation to clean the surface of the solar panel using piezoelectric vibration. All contaminants can be eliminated from this mechanism by using a piezoelectric device in combination with vibration. A wiper fixed to the actuator is driven by a piezoelectric actuator that is linearly travelling on a guide. The actuator can direct the wiper to effectively remove a layer of dust from the surface of the solar panel when there is an appropriate pressure force between the wiper and the panel. Energy gained by the cleaning system. The life of the solar panel reduces due to vibration and this system is not ideal for moisture. as the to eliminate all forms of contaminants without using human labour, only automated water cleaning methods are appropriate. [29]

2.1.3 Coating

Kumar et.al proposed a cleaning system by applying a coat of TiO2 layer on the solar panel glass surface and using harvested water from moisture present in the atmosphere. The system image is shown in figure (3) as below. But, there is no such mechanism which can clean the birds drop and rigid soiling on the solar panel. Moreover, the amount of water extracted from moisture is very less.[3]

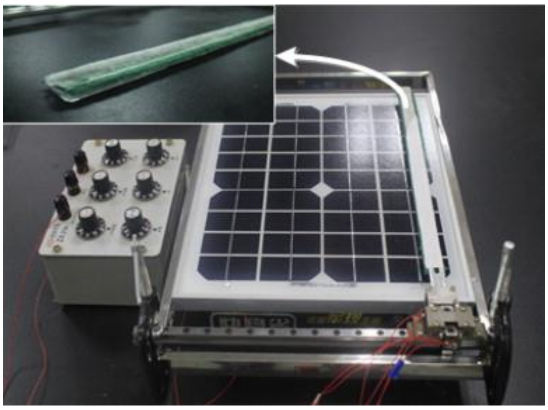


Figure 3. Image of Coating mechanism [1.2]

M.Z. Al-Badra et al. developed an innovative technology for cleaning PV panels that combines antistatic coating with a mechanical vibrator to keep solar panels clean due to the Nano-particles coating. It is hydrophilic and antistatic Nano coating for solar panels and glass. Tin oxide in the coating enhances the panel's coated surface's electrical conductivity and prevents the absorption and adhesion of fine dust and other airborne particles. Nano coating needs to be applied once again after a specific amount of time (six months for desert areas). The coating's manufacturer (Anon, 2020c) concludes that the coating has a one-year lifespan.[18]

2.1.4 Wet and Dry cleaning

In January 2021, Bhatkal, India, Abhishek Naik et al tested an automatic solar panel cleaning system to clean the solar panel surface utilising water cleaning with a cylindrical brush. In this mechanism, a 20-watt solar panel with a maximum output voltage and current of 1.4 amps per is used. A pump that provides water and a 12-volt battery are both attached to a cylindrical brush in this device. The end result is a perfectly clean solar panel and an improvement in maximum power and efficiency of solar panellists of 20 to 30 percent. This method prevents solar panel damage. It failed across dry regions without access to water.[14]

Figure 4. Image of Wet and Dry-cleaning mechanism [1.3]

2.1.5 Electro repulsion method

David V. Chandler investigated the use of electro-repulsion to clean solar panels without the use of water. An electrode passes just above the solar panel surface, imparting an electrical charge to the dust particles, which are then ejected by a charge applied to the panel itself, resulting in surface cleaning, when a high ac voltage is applied to the parallel screen electrodes placed on a solar panel to activate the system. Therefore, only light dust particles were removed. This approach is only effective for cleaning sand and is incapable of cleaning bird droppings. Due of lack of electricity, this experiment cannot be used during the monsoon.[2]

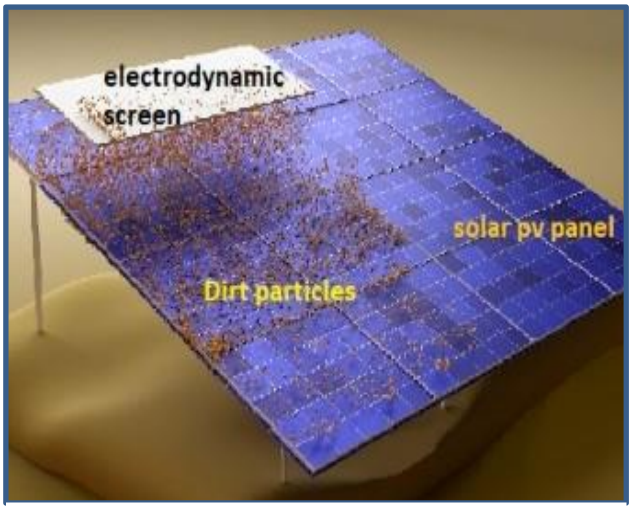


Figure 5. Image of Electro repulsion method mechanism [1.4]

2.2 Comparative Study

Method	Methodology	Limitation	Author
1. Robotic Mechanism	Dry cleaning with robotic arm	unable to remove the bird droppings	Nasib Khadka, DIWAKAR BISTA (IEEE member)
2.Piezoelectric	Piezoelectric vibration	Vibration decreases the life of solar panel	Aayush Bista, Aashish Shresta (IEEE member)
3. Coating	Layer of hydrophobic material	Not suitable for rainy weather	Manoj Kumar Swain, Manohar Mishra,Ramesh C., Shazia Hasan
4. Wet and Dry cleaning	Water cleaning	Wastage of water	Abhishek Naik, Nagesh Naik, Adison Vaaz, Abdul Karim
5. Electro repulsion method	Electrical charge of dust particles	Not suitable for rainy weather	David v. chandler (MIT News office)

Chapter **3**

System Design Methodology

In order to meet all the requirements of the project, it is divided into several stages and phases. The overall aim of the project is to design a smart solar panel that cleans itself automatically and remotely.

3.1 Phase 1

● The first stage of the project was to do primary research in order to check if the project is possible to be made technically.
● The second step that we took is to look into the various sensors, controllers and motors.
● In the next step, we divided the project into categories based on its function. It can be seen that there are two main subsystems on the project and along with this; the project requires some amount of manufacturing and design of mechanical parts to hold the solar panel and the cleaner of the solar panel.
● We started by an AutoCAD sketch of our mechanical structure, so we can build it easily in real life as shown in Figure 6.

3.2 Phase 2

3.2.1 Power consumption by cleaning mechanism

Maximum power produce by solar panel (50w) **=0.2kwh (unit) per day**

(Source - manufacturer of solar panel)

- **components power utilization**

Dc motor- 3.6 watt for 1 motor	(4 x 3.6= 14.4 watt)
Submersible water pump	18watt
Circuit boards	5watt
Total power consumption	**37.4 watt**

- Motor rotational speed(N)= **10rpm**

Velocity of cleaning mechanism (S) = $\frac{\pi * D * N}{60}$

$= \frac{\pi * 0.07 * 10}{60}$

= **0.0366m/s**

Time for 1 cycle (forward & backward stroke) = $\frac{Distance\ traveled\ by\ cleaning\ mechanism}{velocity\ of\ mechanism}$

$=\frac{0.658*2}{0.066}$

= **0.6minutes**

- Considering Worst case cleaning scenario will take 3 cycles

(It is assumed that to clean the surface of solar panel maximum three forward & backward strokes are required)

Maximum operation time = **1.8 minutes**

- Power required to run mechanism (one operation**)-<u>0.001122kwh</u>**

- 3 cleaning operation per day that will consume

0.001122kwh*3= 0.003366kwh (1.6% of power production)

3.2.2 <u>Calculation for 1.1kw solar PV system</u>

❖ Solar panel Specification

Solar panel Wattage	**Amount of Solar panel**	**Total wattage**	**Size of each panel**	**Price**
550 watts	*2	1.1KW	2.279*1.134*0.035 m	Rs.87500

Calculation: -

- Motor rotational speed(N)= **10rpm**

Velocity of cleaning mechanism (S) = $\frac{\pi*D*N}{60}$

$= \frac{\pi*0.07*10}{60}$

= **0.0366m/s**

Time for 1 cycle (forward & backward stroke) = $\frac{2*Distance\ traveled\ by\ cleaning\ mechanism}{velocity\ of\ mechanism}$

$$= \frac{2.279*2}{0.0366}$$

= **2.07minutes**

- Considering Worst case cleaning scenario will take 3 cycles

(It is assumed that to clean the surface of solar panel maximum three forward & backward strokes are required)
Maximum operation time = **6.21minutes**

- Power required to run mechanism (one operation)**-<u>0.00594kwh</u>**

- 3 cleaning operation per day that will consume

0.00594kwh*3= 0.01782kwh **(0.4455% of power production)**

3.2.3 <u>Calculation for 1 month: -</u>

Maximum power output in a day by PV panel = 4kwh

For 1 month = No. of days * Average daily power production
= 30*4
= **120kwh**

If the cleaning is not performed for 1 month than output power obtained
= Monthly power production* efficiency without cleaning
=70kwh (as 50-60% efficiency reduces)

After the use of cleaning mechanism efficiency can be achieved up to **80-85%**.

Maximum power production = $\frac{monthly\ power\ production*maximum\ panel\ efficiency}{100}$

$$= \frac{\mathbf{120*80}}{\mathbf{100}}$$

= 96kwh get produced.

Increase in power production with cleaning mechanism
= power production with cleaning- power production without cleaning
=96-70- 0.5346
=25.4654 kwh(unit)
Hence, 25.4654 kwh(unit) production can be increased by installing cleaning mechanism.

Table 3.1. System Description

PARTS	SPECIFICATIONS	FEATURES	Quantity	Estimated cost
1.Solar panel	Maximum power -50w Vmp- 17.7 v, Imp- 2.84 a Dimension size- 61cm x 65cm	To covert solar energy in to electrical energy	1	-
2.Frame	Material –Mild steel	To support the components	1	Rs.2000
3.Guideways	Material – Mild steel	Guide the wheels	2	-
3.Submersible pump	18watt Hmax-1.6meters Weight-375gms	To deliver the water at required height	1	Rs.600
4.DC motor	Gear Type: Plastic RPM: 100 Working Voltage (VDC): 4-12V (12V recommended and maximum) Torque (kg - cm): 5 Load Current Max: 300mA No-Load Current (mA): 60mA	To rotate the wheels & brush	4	Rs.720 (180X4)
5.Brush	Nylon fiber (Dia-125mm, Length- 620mm)	To clean the dust	1	RS.500
6. Arduino	Arduino Nano V3	To control the process	1	RS.900
7. Camera sensor	Cloud base camera	Click the photos of the dust	1	RS.2000
8. Guiding wheel	Material- fiber Dia-70mm, Thickness-20mm	To drive the cleaning mechanism	4	RS.360 (90X4)
9.Supporting wheels	Material-Plastic Dia- 30mm, Slot Thickness-4mm	To hold the Cleaning Mechanism	4	RS.200 (50X4)
	Miscellaneous cost (Rs.1000)			**Total cost** = Rs.8280

3.3 Cad model of frame

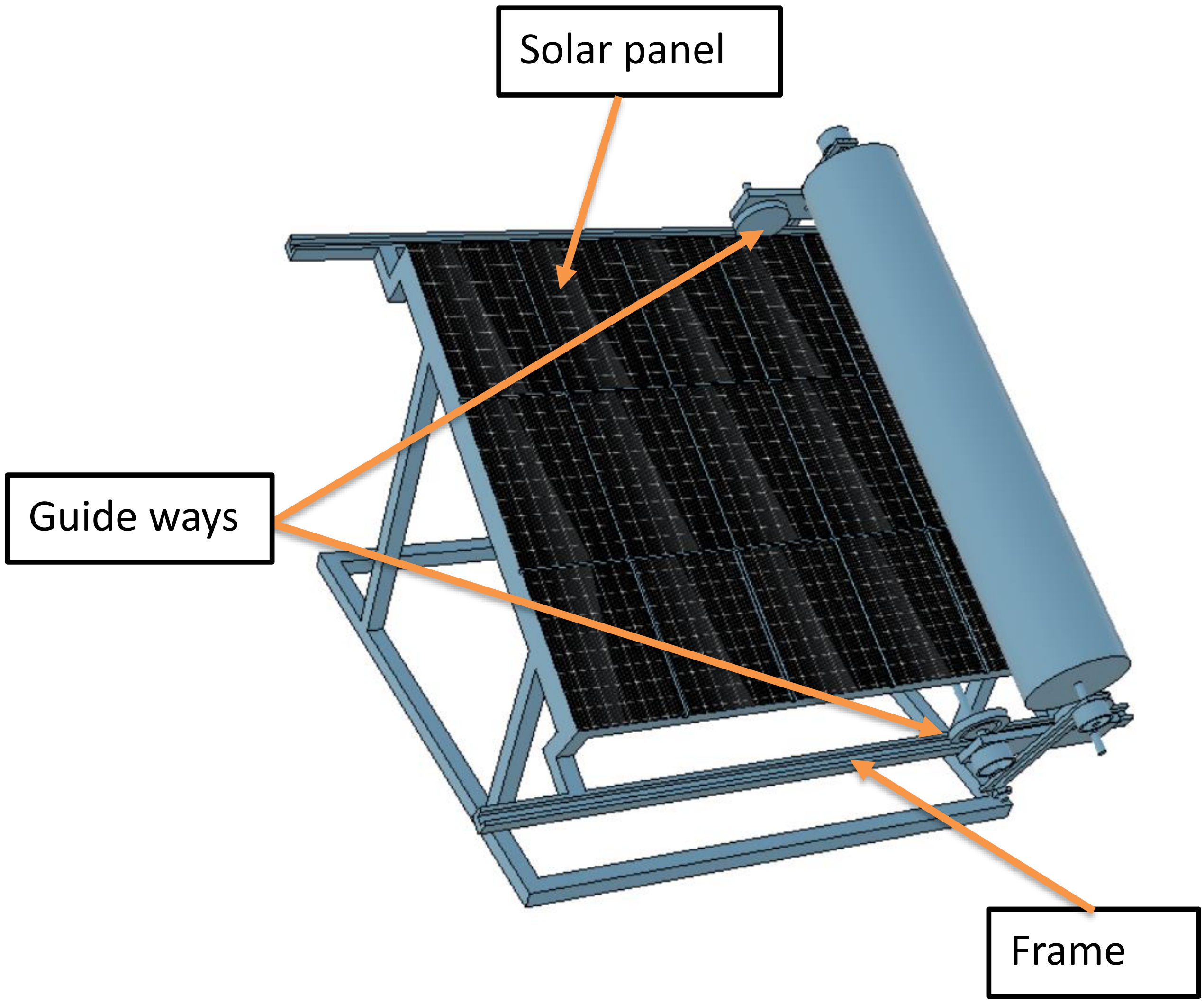


Figure 6. Frame Structure

Fitting the solar panel on frame

In order to prevent any sunlight obstruction, the solar panel is adjusted on the framework. The frame is made out of mild steel. To move the wheel and mechanism, guideways are provided on the frame. For optimum sunlight to reach the solar panel throughout the day, the frame is tilted at a 23-degree angle.

3.4 Cad model of cleaning mechanism

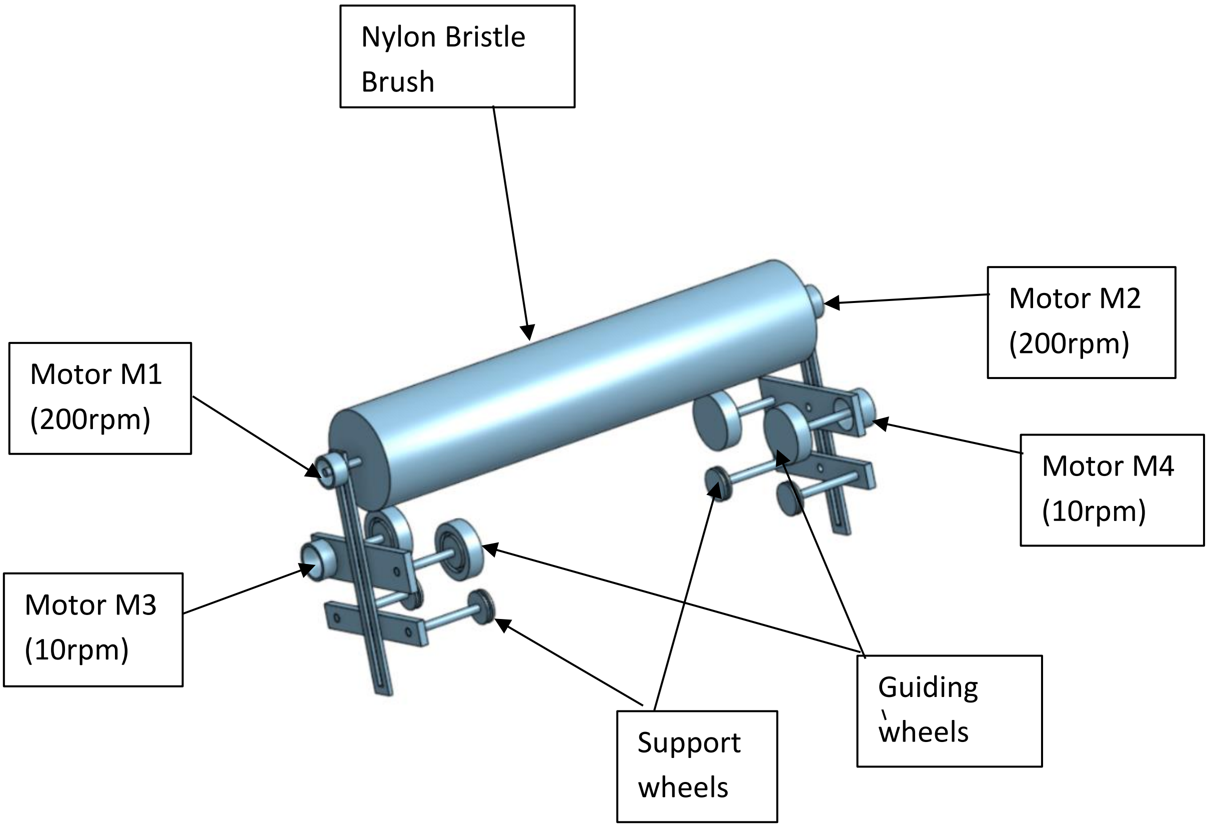


Figure 7. Cad Model of brush holder

A brush for cleaning is included in the mechanism and will rotate with the help of dc motors. Guiding wheels and supporting wheels make up the mechanism. DC motors power the guiding wheels. The wheels will roll along guideways as the rotating brush is being cleaned, providing translating motion.

One cleaning operation takes place by the transverse motion of the mechanism in two strokes

1. Forward stroke (left end to right end) – brush is rotate in anticlockwise direction.
2. Backward stroke (right end to left end) - brush is rotate in clockwise direction.

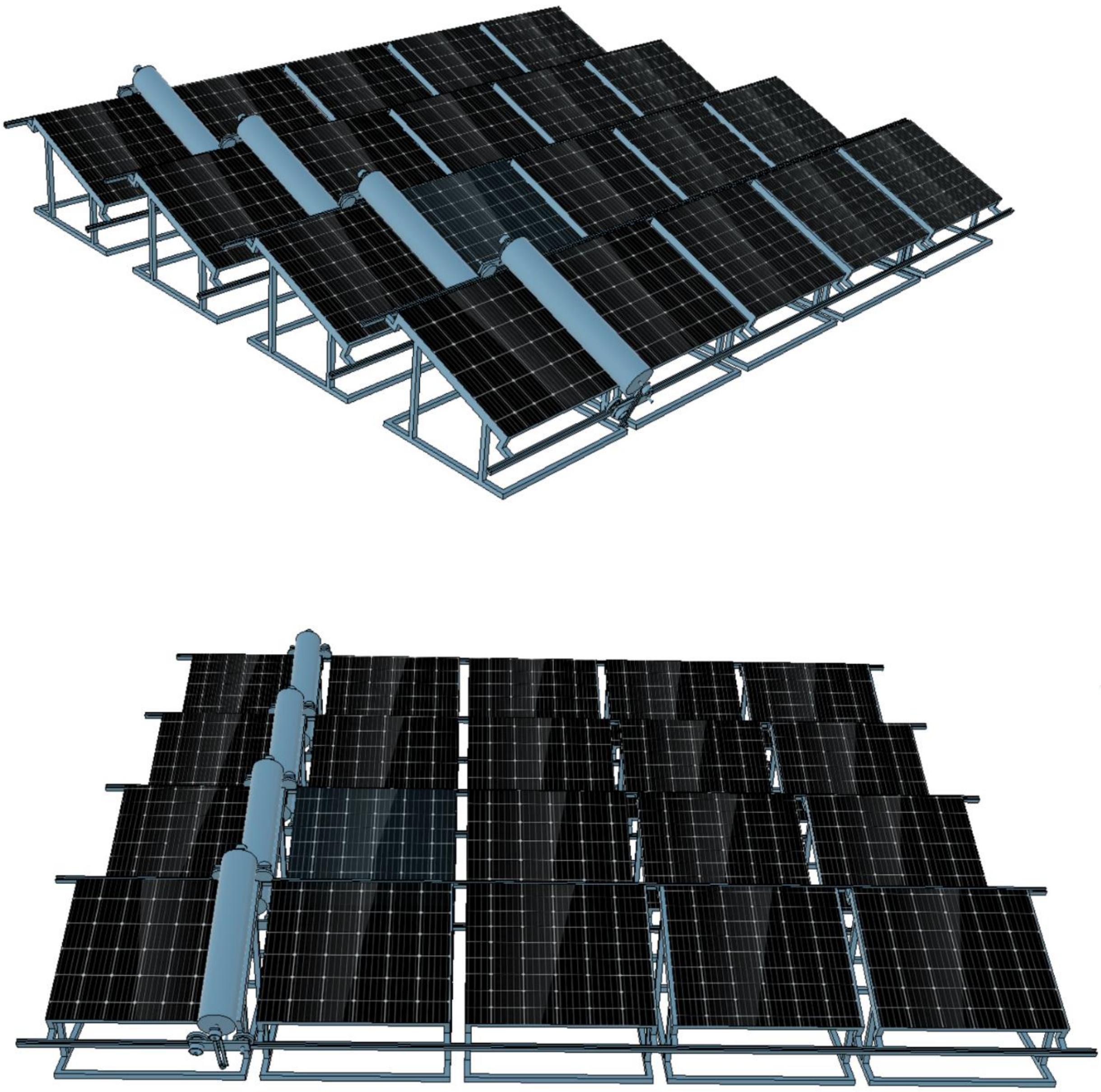


Figure 8. Multi mechanism for multi solar row

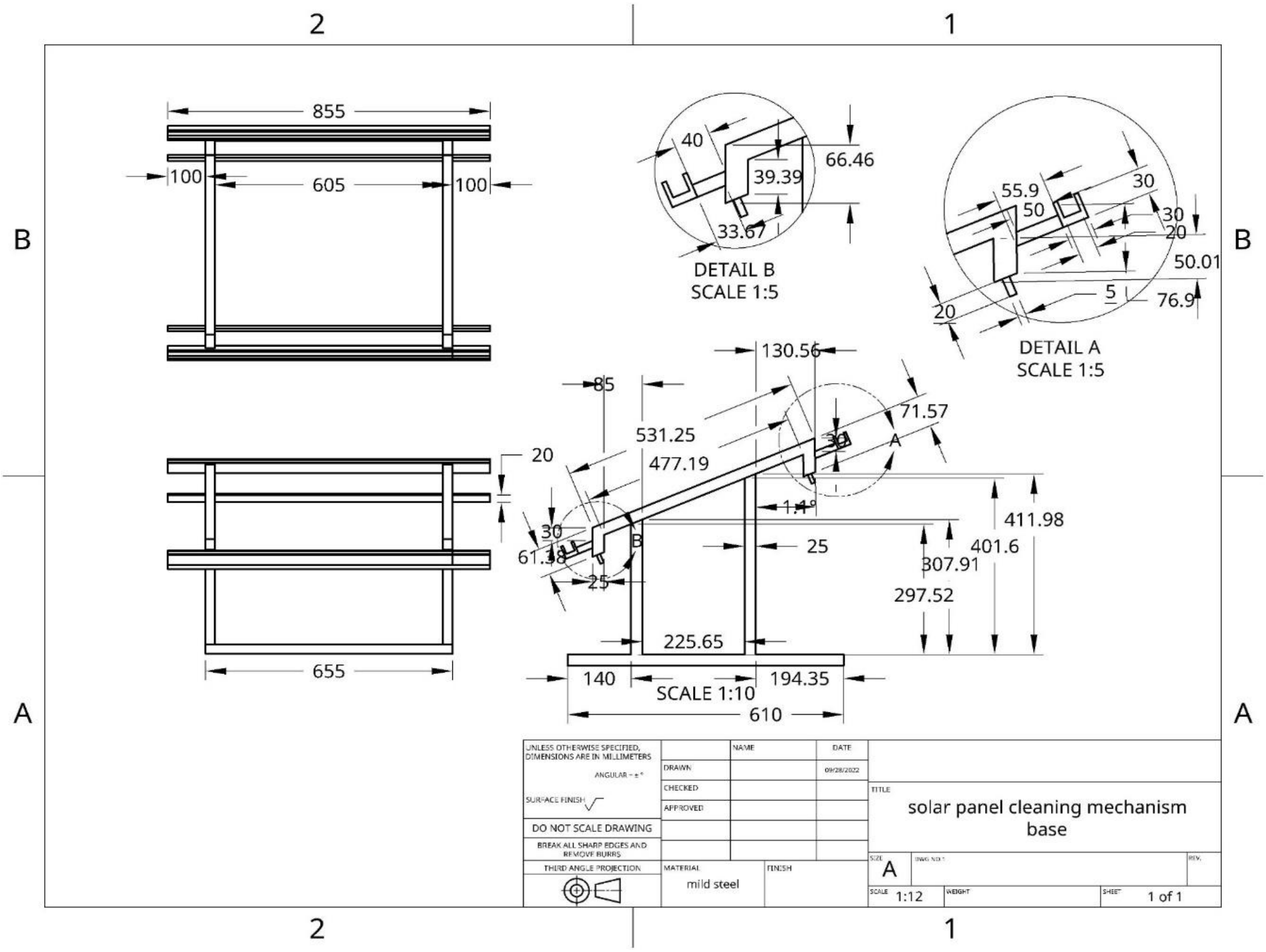


Figure 9. Part Drawing of the frame and Guideways.

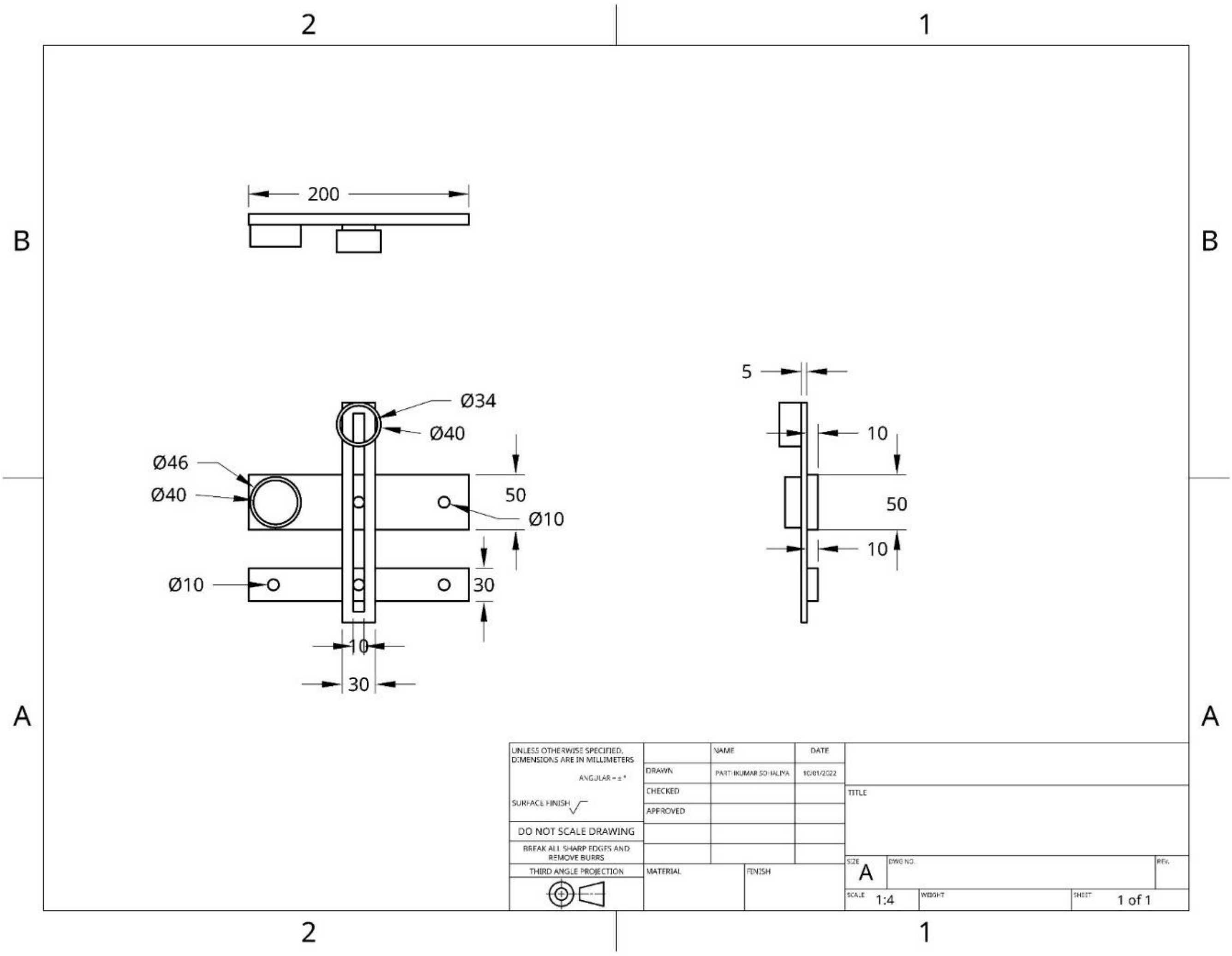


Figure 10. Part Drawing of the Brush and motors holder.

Chapter **4**

Circuit Diagram & System Programming

4.1 Electrical Circuit Diagram of mechanism

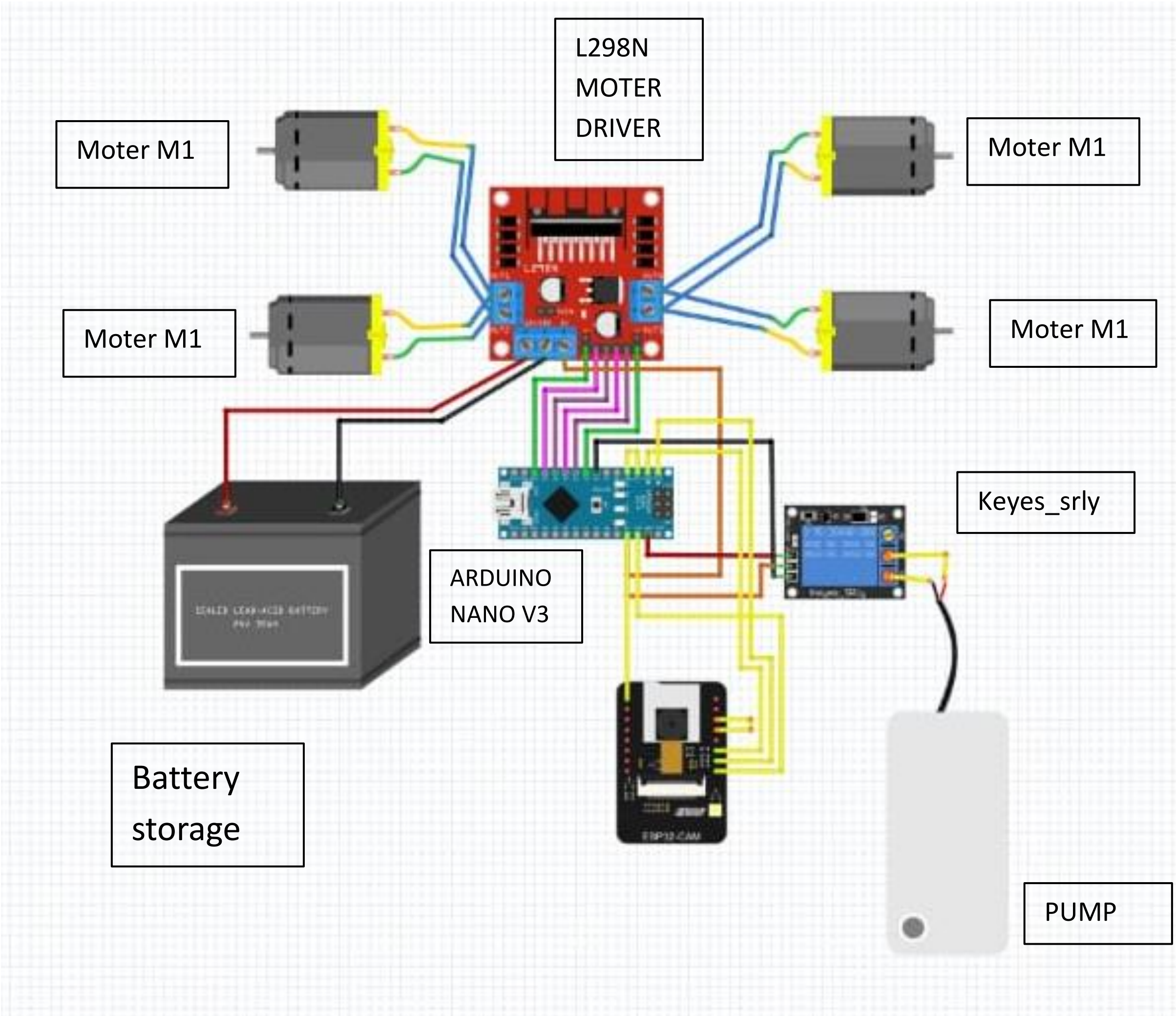


Figure 11. Electric Circuit Diagram

As shown in figure 4. Dc power supply is provided to power all the electric components of the system. Four motors are controlled by Arduino via motor driver L298N. Pump to supply the water is also controlled by the Arduino board.

4.2 Arduino Source Code

```
#code

#include<AFmotor.h>
AF_DCMotor motor1(1);
AF_DCMotor motor2(2);
AF_DCMotor motor3(3);
AF_DCMotor motor4(4);

Void setup()
{
Motor1.setSpeed(600);
Motor2.setSpeed(7);
Motor3.setSpeed(600);
Motor4.setSpeed(7);

Motor1.run(RELEASE);
Motor2.run(RELEASE);
Motor3.run(RELEASE);
Motor4.run(RELEASE);
}

Void loop()
{
Motor1.run(FORWARD);
Motor2.run(BACKWARD);
Motor3.run(BACKWARD);
Motor4.run(FORWARD);
Delay(26500);

Motor1.run(RELEASE);
Motor2.run(RELEASE);
Motor3.run(RELEASE);
Motor4.run(RELEASE);
delay(5000);

Motor1.run(BACKWARD);
Motor2.run(FORWARD);
Motor3.run(FORWARD);
Motor4.run(BACKWARD);
Delay(26500);


Motor1.run(RELEASE);
Motor2.run(RELEASE);
Motor3.run(RELEASE);
```

```
Motor4.run(RELEASE);
Delay(5000);
}
```

4.3 Flow of Cleaning Mechanism

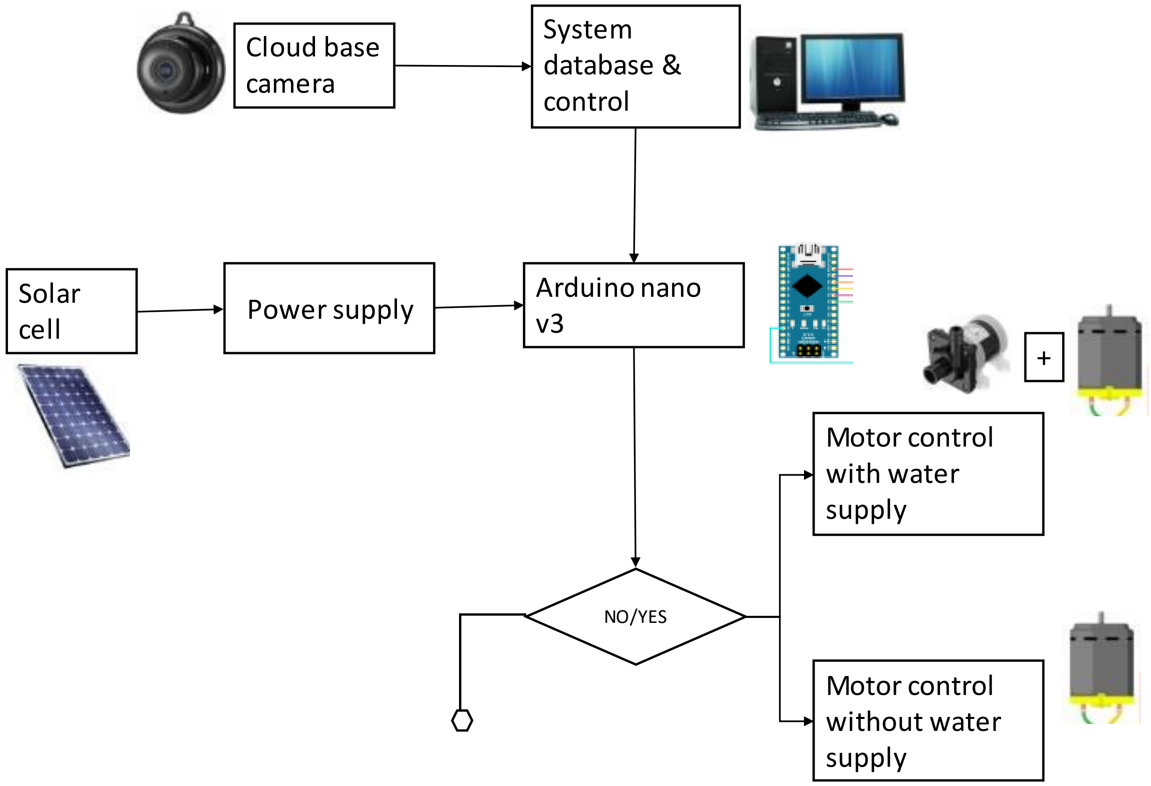


Figure 12. Flow Diagram

The Camera takes the images of the dull solar panel and send the data to the system database. At the system the AI algorithm will do the comparison to figure out type of dust and whether to clean the panel or not. Now the Arduino will get the signal from the system to clean with water or without the water.

4.4 Machine Learning Code

4.4.1 Machine Learning Based Image Processing

Image processing is the process of converting an image to a digital format and then performing various operations on it to gather useful information. Artificial Intelligence (AI) and Machine Learning (ML) has had a huge influence on various fields of technology in recent years. Computer vision, the ability for computers to understand images and videos on their own, is one of the top trends in this industry. The popularity of computer vision is growing like never before and its application is spanning across industries like automobiles, consumer electronics, retail, manufacturing and many more.

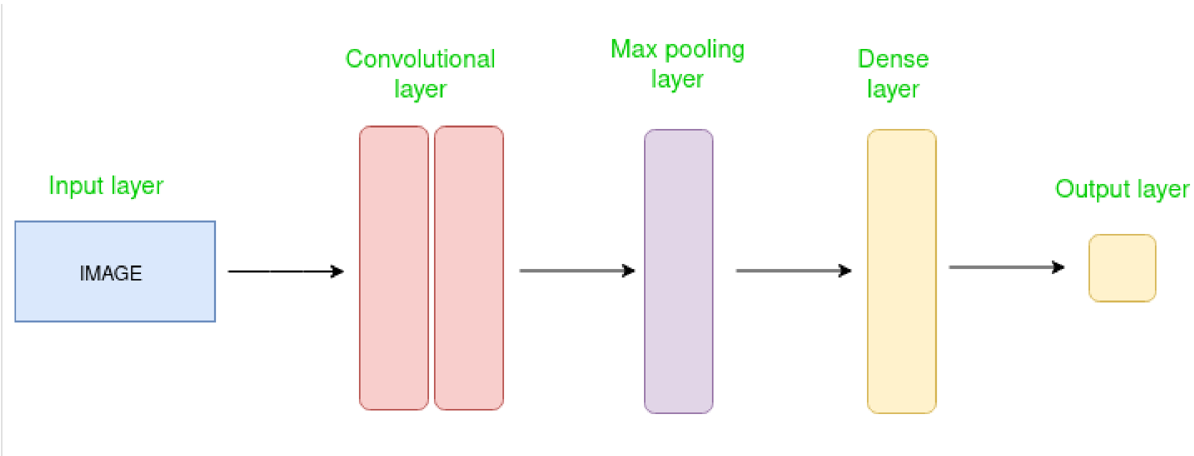
Image processing can be done in two ways: Physical photographs, printouts, and other hard copies of images being processed using analogue image processing and digital image processing is the use of computer algorithms to manipulate digital images. The input in both cases is an image. The output of analogue image processing is always an image. However, the output of digital image processing may be an image or information associated with that image, such as data on features, attributes, and bounding boxes.

4.4.2 Convolutional Neural Networks

A Convolutional Neural Network (CNN) is a type of Deep Learning neural network architecture commonly used in Computer Vision. Computer vision is a field of Artificial Intelligence that enables a computer to understand and interpret the image or visual data. Convolutional Neural Network (CNN) is the extended version of artificial neural networks (ANN) which is predominantly used to extract the feature from the grid-like matrix dataset. For example visual datasets like images or videos where data patterns play an extensive role.

4.4.3 CNN Architecture

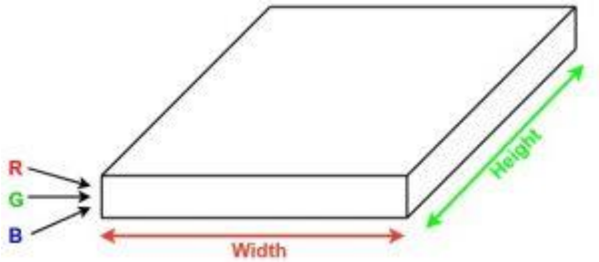
Convolutional Neural Network consists of multiple layers like the input layer, Convolutional layer, Pooling layer, and fully connected layers.



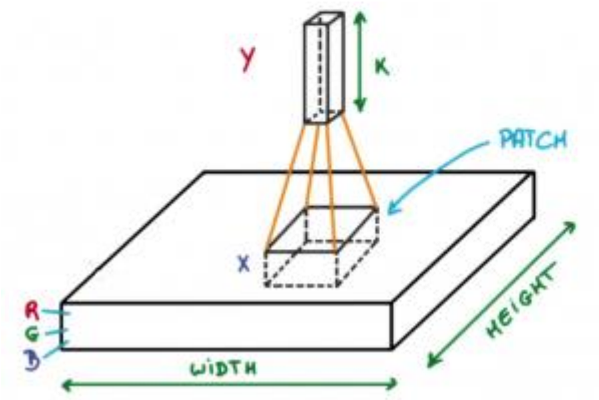
The Convolutional layer applies filters to the input image to extract features, the Pooling layer down sample the image to reduce computation, and the fully connected layer makes the final prediction. The network learns the optimal filters through backpropagation and gradient descent.

4.4.4 Convolutional layer working

Convolution Neural Networks or covnets are neural networks that share their parameters. Imagine you have an image. It can be represented as a cuboid having its length, width (dimension of the image), and height (i.e the channel as images generally have red, green, and blue channels).



Now imagine taking a small patch of this image and running a small neural network, called a filter or kernel on it, with say, K outputs and representing them vertically. Now slide that neural network across the whole image, as a result, we will get another image with different widths, heights, and depths. Instead of just R, G, and B channels now we have more channels but lesser width and height. This operation is called Convolution. If the patch size is the same as that of the image it will be a regular neural network. Because of this small patch, we have fewer weights.



Now let’s talk about a bit of mathematics that is involved in the whole convolution process.

Convolution layers consist of a set of learnable filters (or kernels) having small widths and heights and the same depth as that of input volume (3 if the input layer is image input).

For example, if we have to run convolution on an image with dimensions 34x34x3. The possible size of filters can be axax3, where ‘a’ can be anything like 3, 5, or 7 but smaller as compared to the image dimension.

During the forward pass, we slide each filter across the whole input volume step by step where each step is called stride (which can have a value of 2, 3, or even 4 for high-dimensional images) and compute the dot product between the kernel weights and patch from input volume.

As we slide our filters we'll get a 2-D output for each filter and we'll stack them together as a result, we'll get output volume having a depth equal to the number of filters. The network will learn all the filters.

Layers used to build ConvNets

A complete Convolution Neural Networks architecture is also known as covnets. A covnets is a sequence of layers, and every layer transforms one volume to another through a differentiable function.

Types of layers: datasets

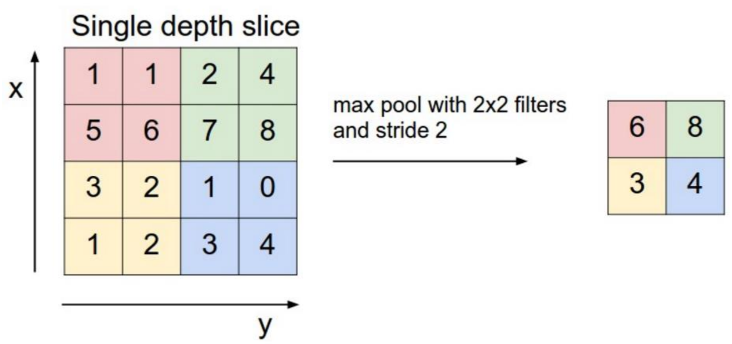
Let's take an example by running a covnets on of image of dimension 32 x 32 x 3.

Input Layers: It's the layer in which we give input to our model. In CNN, Generally, the input will be an image or a sequence of images. This layer holds the raw input of the image with width 32, height 32, and depth 3.

Convolutional Layers: This is the layer, which is used to extract the feature from the input dataset. It applies a set of learnable filters known as the kernels to the input images. The filters/kernels are smaller matrices usually 2×2, 3×3, or 5×5 shape. it slides over the input image data and computes the dot product between kernel weight and the corresponding input image patch. The output of this layer is referred ad feature maps. Suppose we use a total of 12 filters for this layer we'll get an output volume of dimension 32 x 32 x 12.

Activation Layer: By adding an activation function to the output of the preceding layer, activation layers add nonlinearity to the network. it will apply an element-wise activation function to the output of the convolution layer. Some common activation functions are RELU: max(0, x), Tanh, Leaky RELU, etc. The volume remains unchanged hence output volume will have dimensions 32 x 32 x 12.

Pooling layer: This layer is periodically inserted in the covnets and its main function is to reduce the size of volume which makes the computation fast reduces memory and also prevents overfitting. Two common types of pooling layers are max pooling and average pooling. If we use a max pool with 2 x 2 filters and stride 2, the resultant volume will be of dimension 16x16x12.



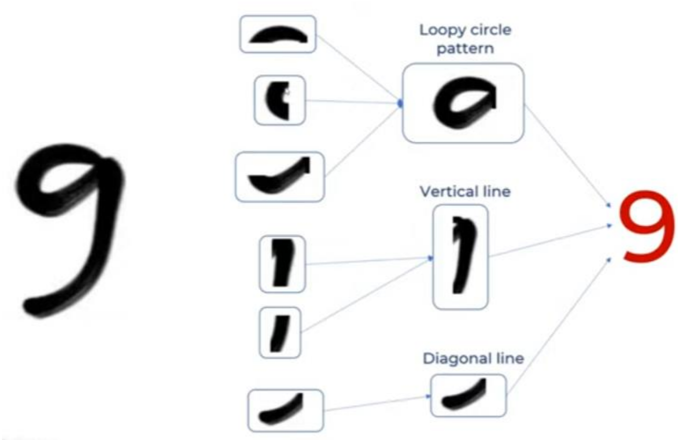
Flattening: The resulting feature maps are flattened into a one-dimensional vector after the convolution and pooling layers so they can be passed into a completely linked layer for categorization or regression.

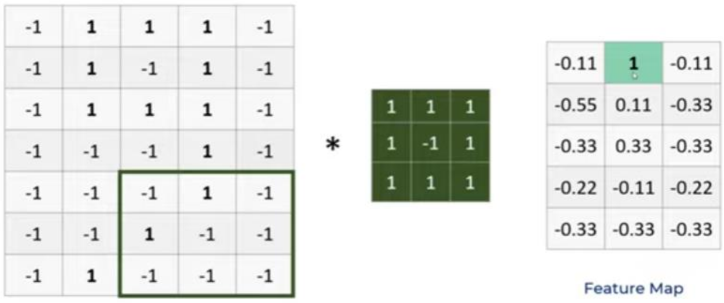
Fully Connected Layers: It takes the input from the previous layer and computes the final classification or regression task.

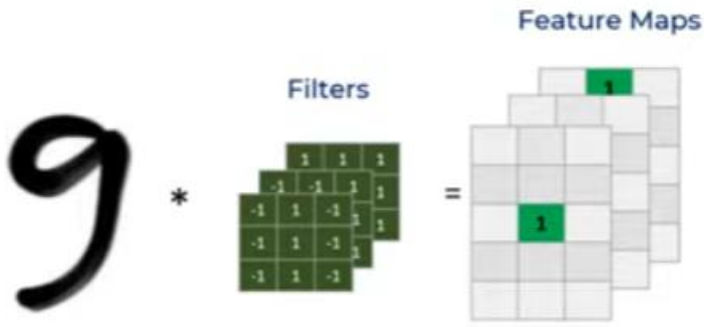
Output Layer: The output from the fully connected layers is then fed into a logistic function for classification tasks like sigmoid or softmax which converts the output of each class into the probability score of each class

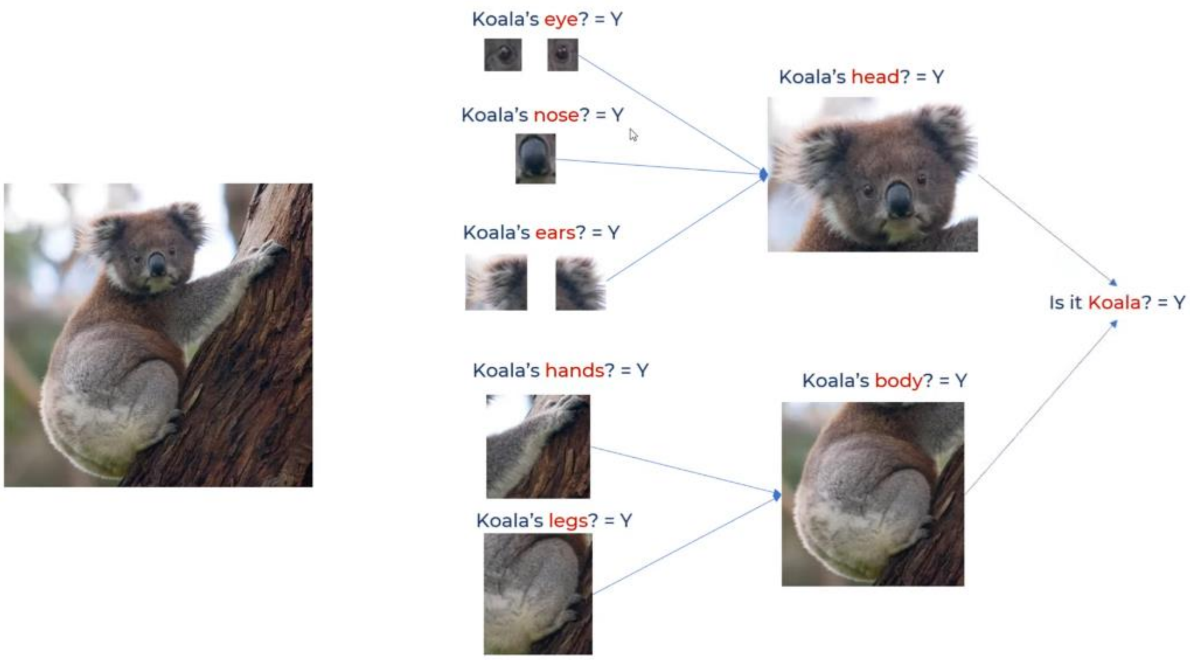
4.4.5 How its works in Our project

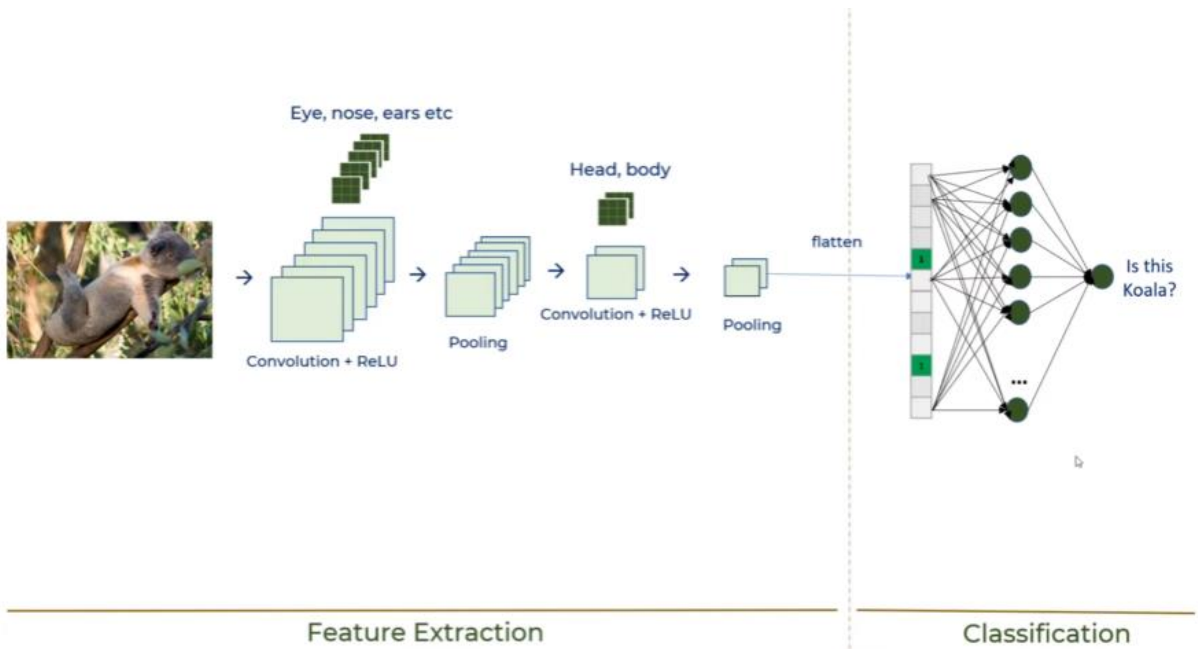
The CNN model used in our project is used to classify the solar panel image into three categories like "Clean", "Dusty – need dry cleaning" and "Dusty – need wet cleaning". The CNN model in which the feature is extracted from the clean and dusty solar panel. Like the Clean will have the clean design of the panel and the dusty will have some features like colour difference and the blockage of the clean solar panel design and many more, which will be detected while training. Then the libraries like TensorFlow, NumPy, Keras, Matplotlib, Pandas are used to manipulate the data generated by the image in the form of the matrix and those will result us in the decimal value which will ultimately give the result of the ML model and depending on the value the type of cleaning will be decided. The no. of layer used in our model are as per the accuracy achieved and the Dataset which we have taken for the Training the model is form the Kaggle and we have trained our model with 1493 cleaned solar panel images and 1069 Dusty solar panel images. The model accuracy is achieved to be average 71%, it's low because the dataset we collected is varied by different angles they have been captured. The model accuracy can be increased by cropping the image to just the solar panel and then training, which results in to higher accuracy like more than 95%. The below given is just the **glimpse how our model is trained with the help of the examples like "hand written 9" and the "image of the animal**".



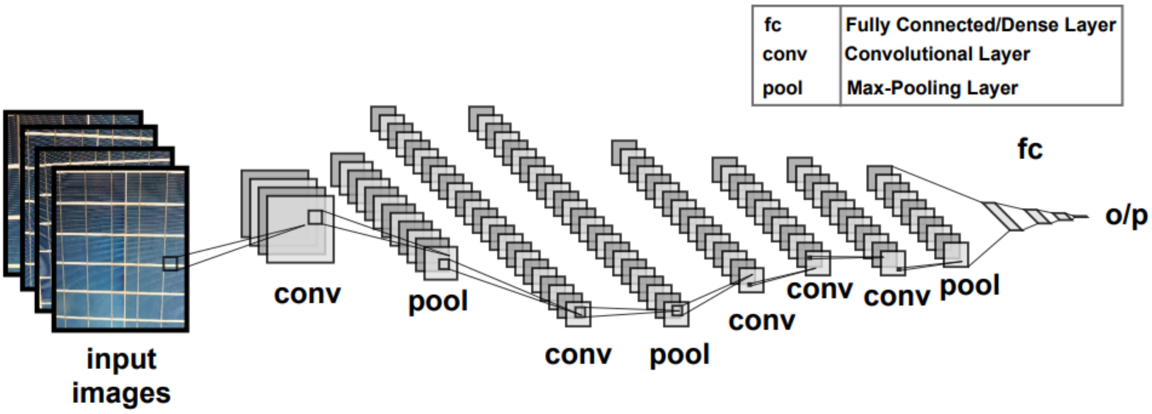

-1 1 1 1 -1
-1 1 -1 1 -1
-1 1 1 1 -1
-1 -1 -1 1 -1
-1 -1 -1 1 -1
-1 -1 1 -1 -1
-1 1 -1 -1 -1
*
1 1 1
1 -1 1
1 1 1
-0.11 1 -0.11
-0.55 0.11 -0.33
-0.33 0.33 -0.33
-0.22 -0.11 -0.22
-0.33 -0.33 -0.33
Feature Map


Feature Maps
Filters
*
=


Koala's eye? = Y
Koala's nose? = Y
Koala's ears? = Y
Koala's head? = Y
Is it Koala? = Y
Koala's hands? = Y
Koala's body? = Y
Koala's legs? = Y


Eye, nose, ears etc
Head, body
Convolution + ReLU
Pooling
Convolution + ReLU
Pooling
flatten
Is this Koala?
Feature Extraction
Classification

Now for our we can also extract the features for the clean and dusty panel by training the ML model with the Thousands of image dataset. The image can have variation in the thickness and rotation. That problem can be solved by the augmentation. (Augmentation means rotation of the image to the specific angle so the CNN model can extract feature and classify). Here the Convolution layer, Relu Layer, Pooling Layer are used for the below given purpose. Relu helps with making the model nonlinear (like negative values in the matrix are replaced by 0). But still the there is too much computation - for that we do Pooling. The Pooling layer is used to reduce the size. They are of 3 types Max, Min, Avg.



- **Advantages of Convolution**

  Connections sparsity reduces overfitting

  Conv + pooling gives location invariant feature detection

  Parameter sharing

- **Advantages Relu**

  Introduces non linearity

  Speeds up training, faster to compute

- **Advantages Pooling**

  Reduces dimensions and computation

  Reduces overfitting

CNN for the rotated and scaled samples.

You need to have rotated, scaled samples in training dataset. If you don't have such samples than use data augmentation methods to generate new rotated/scaled samples from existing training samples. This filter will be learned by the network by it's own automatically by training. Using very high number of data and backpropogation technique it will figure out the right number of filters.

The SMS service for alerting the user at specific interval set by the user for the type of cleaning required.

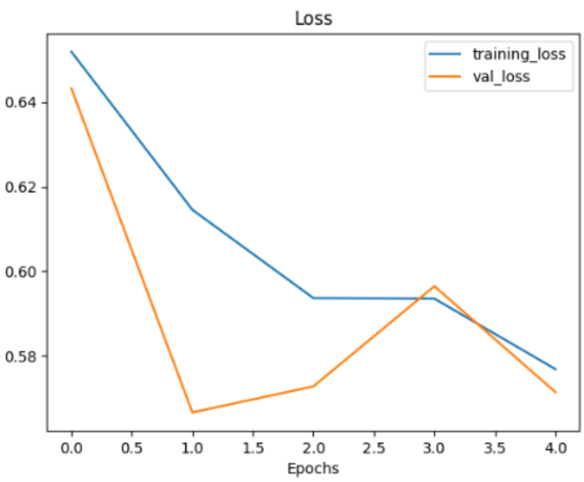
We use the SMS service by the online platform Twilio which is free to use and they also have the library in python so that the output of the machine learning model is send to the specified number and then the user can take the required action based on the output of the ML model. Such action are then given to the Arduino and according the Arduino will do the type of cleaning.

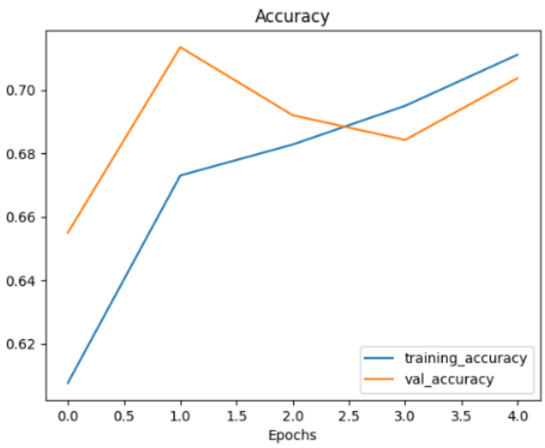
Code for the ML model

```
model_8 = Sequential([
  Conv2D(10, 3, activation='relu', input_shape=(224, 224, 3)), # same input shape as our images
  Conv2D(10, 3, activation='relu'),
  MaxPool2D(),
  Conv2D(10, 3, activation='relu'),
  Conv2D(10, 3, activation='relu'),
  MaxPool2D(),
  Flatten(),
  Dense(1, activation='sigmoid')
])

# Compile the model
model_8.compile(loss="binary_crossentropy",
                optimizer=tf.keras.optimizers.Adam(),
                metrics=["accuracy"])

# Fit the model
history_8 = model_8.fit(train_data_augmented_shuffled,
                        epochs=5,
                        steps_per_epoch=len(train_data_augmented_shuffled),
                        validation_data=test_data,
                        validation_steps=len(test_data))
```

Accuracy of the model and it's Plot

```
Epoch 1/5
65/65 [==============================] - 452s 7s/step - loss: 0.6519 - accuracy: 0.6076 - val_loss: 0.6432 - val_accuracy: 0.6550
Epoch 2/5
65/65 [==============================] - 115s 2s/step - loss: 0.6145 - accuracy: 0.6730 - val_loss: 0.5666 - val_accuracy: 0.7135
Epoch 3/5
65/65 [==============================] - 113s 2s/step - loss: 0.5937 - accuracy: 0.6828 - val_loss: 0.5728 - val_accuracy: 0.6920
Epoch 4/5
65/65 [==============================] - 124s 2s/step - loss: 0.5935 - accuracy: 0.6950 - val_loss: 0.5965 - val_accuracy: 0.6842
Epoch 5/5
65/65 [==============================] - 114s 2s/step - loss: 0.5769 - accuracy: 0.7111 - val_loss: 0.5714 - val_accuracy: 0.7037
```





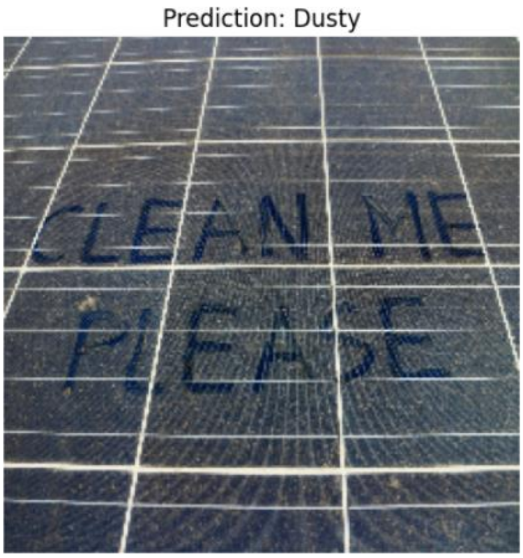
```python
# Importing necessary libraries
import os
import glob
import time
# Function to retrieve the last image inserted to the folder
def get_last_uploaded_image():
  # Set the path to the folder where images are stored
  path = '/content/drive/MyDrive/DriveSyncFiles/'

  # Get the list of all image files in the folder
  files = sorted(glob.glob(os.path.join(path, '*.jpg')))

  # Get the last image file from the list
  latest_file = files[-1]

  # Print the path of the last image file
  print('Last image uploaded:', latest_file)
  return latest_file

def run_model_on_last_uploaded_image():
  last_file = get_last_uploaded_image()
  # Test our model on a custom image
  pred_and_plot(model_8, last_file, ['Clean','Dusty'])

# Run the model continuously with a sleep time of 5 seconds to check for the last uploaded image

while True:
  # Get the list of all files in the folder
  file_list = os.listdir(folder_path)
  # Check if any new file has been added since the last iteration
  if len(file_list) > 0:
    # Run the machine learning model on the last uploaded image
    run_model_on_last_uploaded_image()
    plt.show()
    # Wait for 5 seconds before checking for the next uploaded image
    time.sleep(120)
```

The code for the SMS service that we used.

```python
# Your Account SID and Auth Token from twilio.com/console
account_sid = 'AC368743a76a26029f693403864ab1ae53'
auth_token = '2ee76e3ec47df298449d858d3b3c4f12'
client = Client(account_sid, auth_token)
# The message you want to send
message = pred_class + " " + output_message
# The phone number you want to send the message to
to_number = '+916353153180'
# The phone number you want to send the message from
from_number = '+16076083726'
# Send the message using the Twilio API
client.messages.create(body=message , from_=from_number , to=to_number)
```

The output of the ML model

```
Last image uploaded: /content/drive/MyDrive/DriveSyncFiles/1680683524687.jpg
1/1 [==============================] - 0s 23ms/step
```



The SMS at the user end.

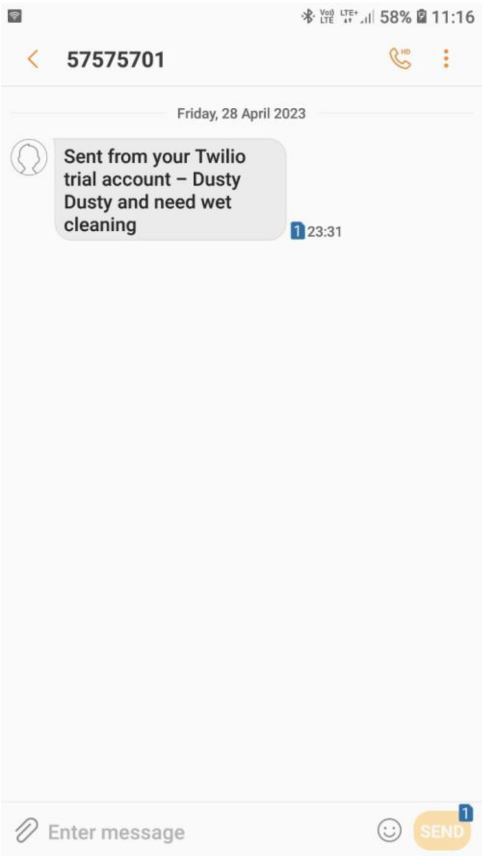
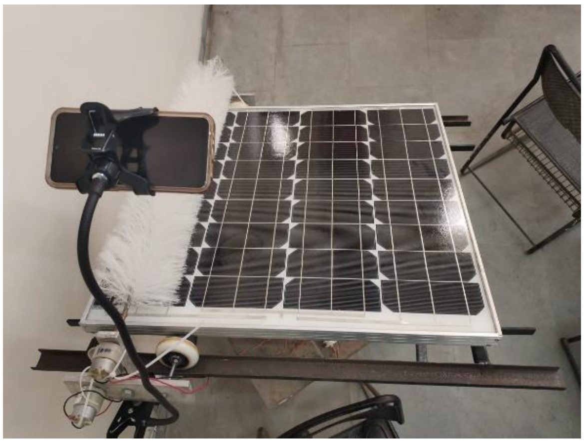


Figure 13. SMS sending by Twilio

Chapter **5**

Fabrication work



Chapter **6**

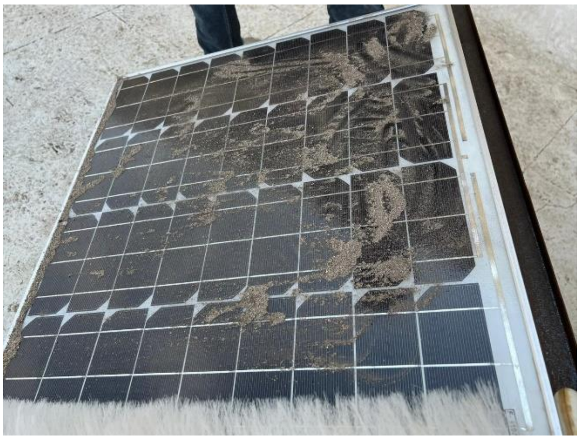
6.1 Result and Discussion

After design and testing the cleaning mechanism, the power consumption by the system to perform one cleaning cycle is 1% of the total power production in a day. The efficiency of the solar panel gets increased by 75-80%. The accuracy of the programme to distinguish is between clean or dirty panel is around 53.33%.

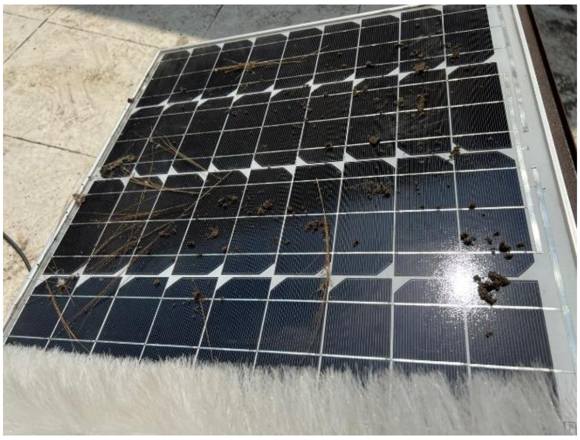
6.1.1 Experimental data for different types of impurities

Weight of dry dust	**Weight of water contain**	**%of moisture contain**	**Required no.of cycles for dry cleaning**	**Power consumption by mechanism (dry) (kwh)**	**Required no. of cycles for wet cleaning**	**Power consumption by mechanism(wet) (kwh)**
300gm	0gm	0%	2	0.000694	1	0.000374
300gm	50gm	14.28%	3	0.001092	1	0.000374
300gm	100gm	25%	Not sufficient	-	2	0.000748
300gm	150gm	33.33%	Not sufficient	-	3	0.001122
300gm	200gm	40%	Not sufficient	-	3	0.001122

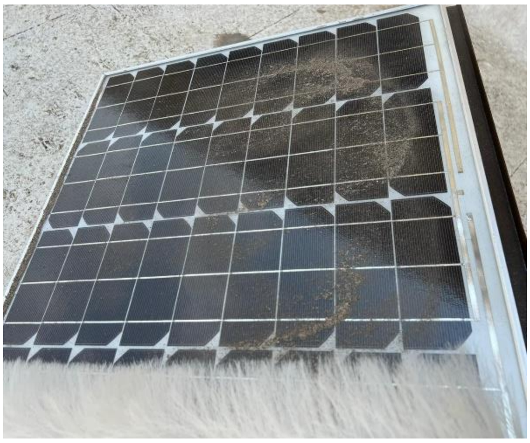
Table 6.1 Power consumption by Mechanism



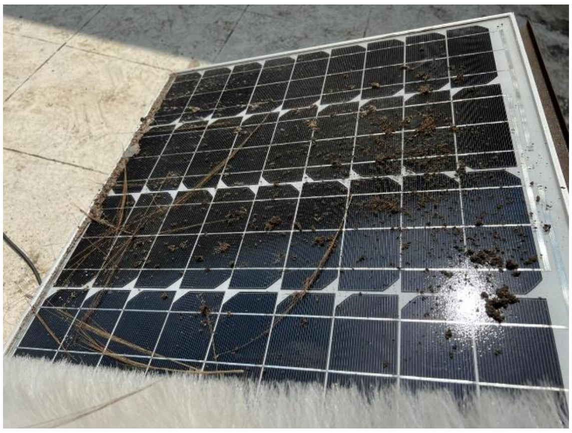
(a) 0% of moisture contain



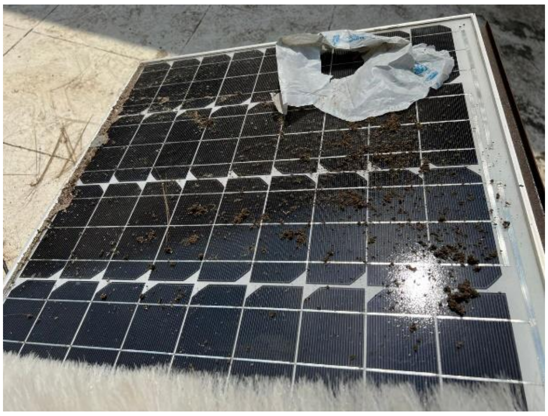
(b) 14.28% of moisture contain



(c) 25% of moisture contain



(d) 33.33% of moisture contain

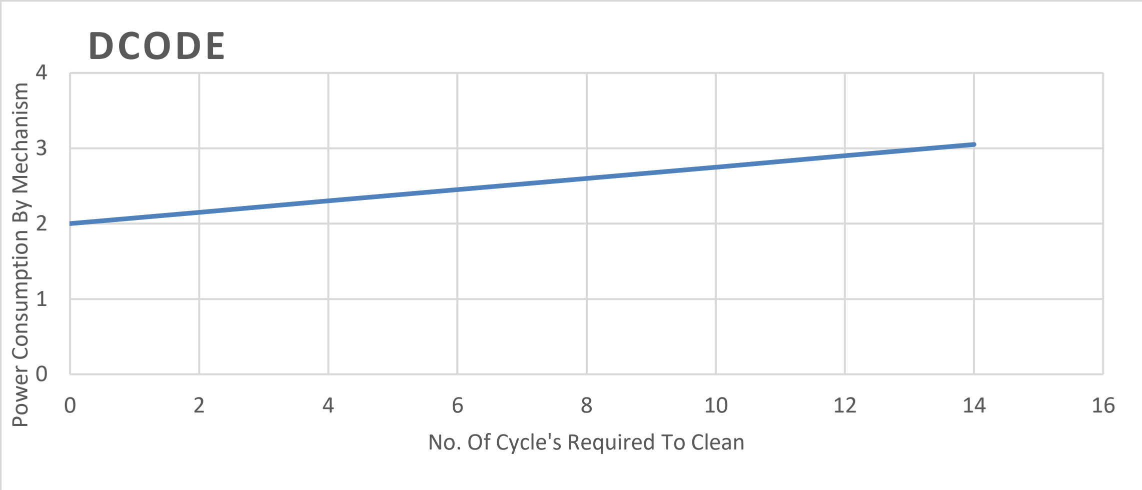


(e) 40% of moisture contain

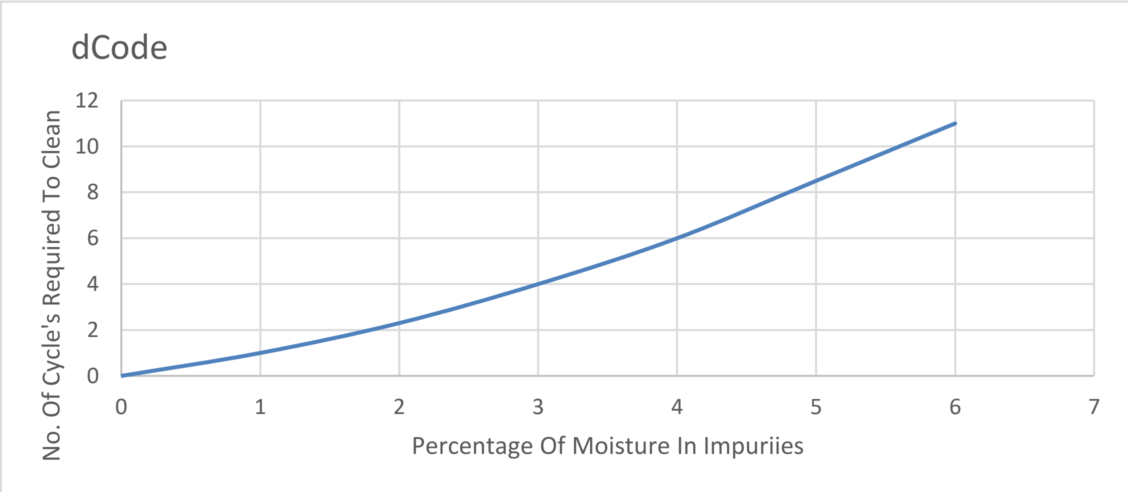
Figure 14. Different type moisture
contains on solar panel

6.2.2 Outcome form the Experiment

1. Dry Cleaning



(a)

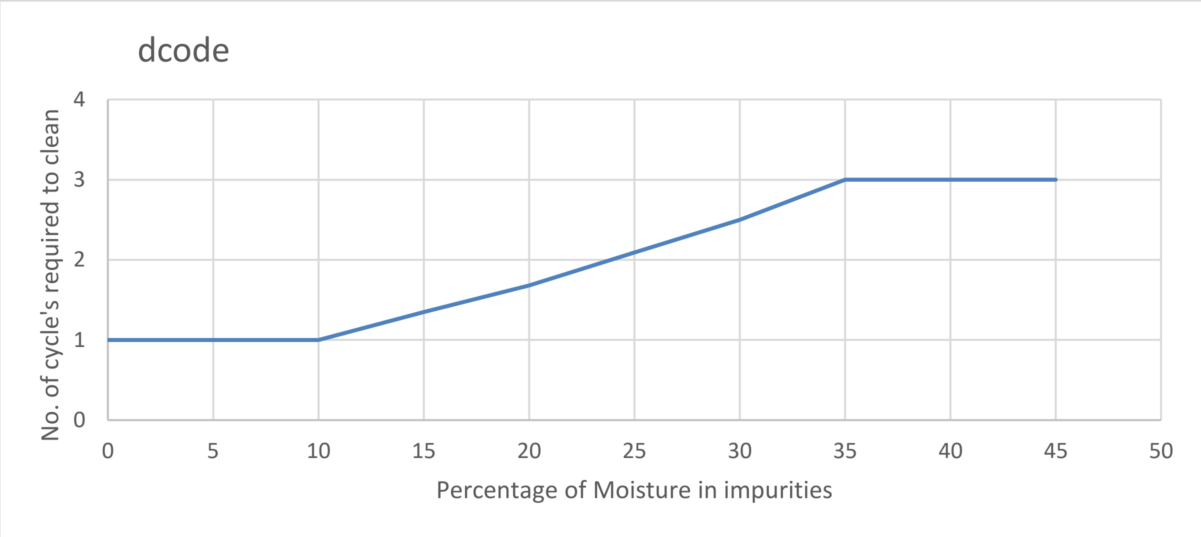


(b)

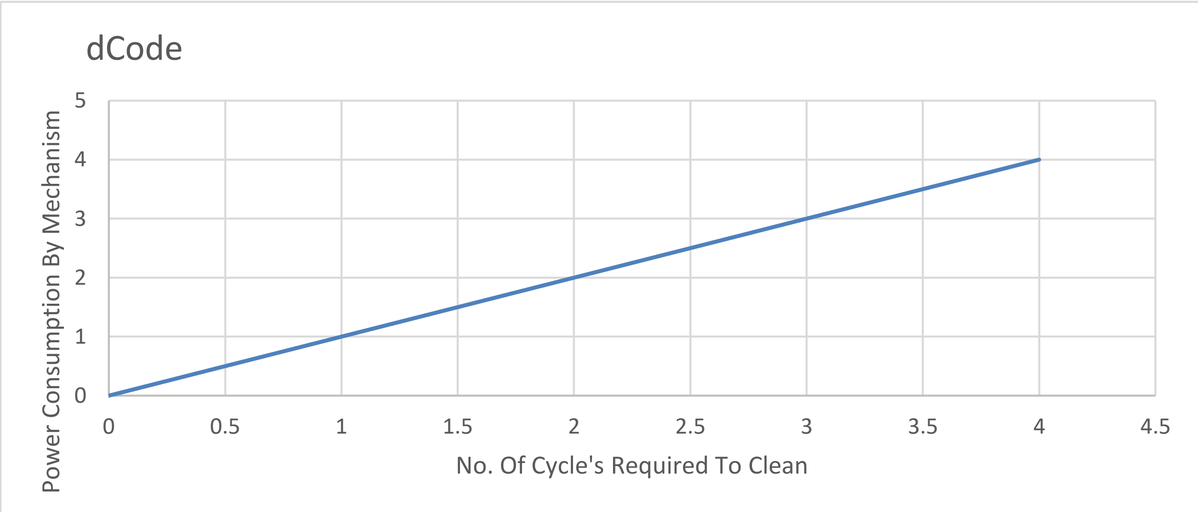
Figure 15. Plots for the Dry Cleaning

As the moisture content in the impurities increases, the number of cycles required to clean the solar panel also increases steadily. This results in a steady growth function, indicating that the graph for the number of cycles required versus the percentage of moisture content will be a straight line. Moreover, power consumption increases exponentially with the number of cleaning cycles because dry cleaning is only effective up to a certain level of moisture content. Beyond that point, dry cleaning is insufficient. The accompanying graphs illustrate these relationships.

2. Wet Cleaning



(a)



(b)

Figure 16. Plots for the Wet Cleaning

The graph plotting moisture content in percentage versus the number of cycles required to clean the solar panel shows a step function. For a certain range of values, the curve is straight, while for another range, an increasing curve is observed (both are seen alternatively). As the moisture content increases, the number of cycles required also increases in a stepwise manner. Conversely, the plot for power consumption by the mechanism versus the number of cycles required to clean the solar panel shows a steadily increasing function (straight line). This is because wet cleaning using water enables the cleaning of the solar panel in fewer cycles compared to dry cleaning, which requires more cycles to clean the surface for the same moisture content. Both of the graphs are presented below for your reference.

The experiment concludes that the efficiency of the mechanism significantly improves from 60 to 70 percent for one cycle to 75 to 80 percent for two to three cycles.

6.2.3 Experiment Reading for before and after solar panel cleaning

Time	**Ambient Temp**	**Solar cell Temp. without cleaning (°C)**	**Voltage (V)**	**Current (A)**	**Power (W)**	**Efficiency**
09:00	32°C	30.10 °C	18.17	1.89	34.341	68.68%
10:00	35°C	31.24 °C	18.83	1.92	36.170	72.34%
11:00	36°C	31.66 °C	19.13	1.91	36.538	73.07%
12:00	37°C	32.96 °C	17.97	2.29	41.136	74.1%
13:00	38°C	33.22 °C	16.18	2.6	42.068	74.89%
14:00	37°C	34.53 °C	16.2	2.57	41.634	74.62%
15:00	36°C	33.89 °C	16.29	2.39	38.933	73.10%
16:00	36°C	32.30 °C	16.5	2.23	36.791	72.32%

Table 6.2 Efficiency before clean the solar panel

Time	**Ambient Temp**	**Solar cell Temp. without cleaning (°C)**	**Voltage (V)**	**Current (A)**	**Power (W)**	**Efficiency**
09:00	32°C	31.47°C	19.1	1.92	36.672	73.34%
10:00	35°C	32.63°C	19.6	1.94	38.024	77.04%
11:00	36°C	32.84°C	19.98	1.99	39.76	79.52%
12:00	37°C	34.26°C	20.4	2.24	45.696	80.89%
13:00	38°C	35.91°C	20.1	2.36	47.436	82.36%
14:00	37°C	36.90°C	19.9	2.29	45.571	81.69%
15:00	36°C	35.78°C	19.7	2.16	42.552	79.86%
16:00	36°C	34.17°C	19.5	1.99	38.805	75.61%

Table 6.3 Efficiency after clean the solar panel

Time	Increase Efficiency
09:00	4.66
10:00	4.7
11:00	6.45
12:00	6.79
13:00	7.47
14:00	7.07
15:00	6.76
16:00	3.29
Average	**5.90**

Table 6.4 Increase the Efficiency

Before cleaning the solar panel, the efficiency ranged from 68.68% to 74.89%, while after cleaning, the efficiency improved and ranged from 73.34% to 82.36%. These results suggest that cleaning solar panels is crucial for maintaining their performance and ensuring maximum energy production.

Furthermore, the data also shows that the solar panel's temperature increased after cleaning, indicating that the accumulated dust and debris were impacting its heat dissipation capability. The increase in temperature is a positive sign, as it suggests that the solar panel is absorbing more sunlight and converting it into usable energy.

In conclusion, cleaning the solar panel leads to a significant improvement in its efficiency and energy production. Therefore, it is important to regularly clean solar panels to ensure their optimal performance and maximum energy generation.

6.2 Conclusion

The Solar Panel Cleaning System project attempts to develop a more effective means of preserving solar efficiency. The primary objective was to create a machine with an appropriate control system that can clean solar panels. This project is a prototype that has been built to tap into a growing market. Along the road, the project team encountered various challenges. Learning how to configure an Arduino Uno, understand how Python affects electrical components, and use AI were all necessary for designing the control system. These new experiences included physical wiring, relays, and soldering boards to construct the proposed circuits. This being said, the project fulfilled the desired design with the planned control and mechanism. The DC motors were controlled by both relays and drivers to accomplish speed and directions control. Also, control code for the DC motors and the water pump were written then implemented in the system.

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[1.1] Figure 1. Image of Robotic (https://hycleaner.eu/wpcontent/uploads/2017/02/hyCLEANER_black_SOLAR_mit_Schlauchaufroller-1100x600.jpg)

[1.2] Figure 3. Image of coating (https://encryptedtbn0.gstatic.com/images?q=tbn:ANd9GcRtGreKafmwHwuau02EuEZ7JdP6WANtp6h9vQ&usqp=CAU)

[3] Figure 4. Image of Wet and Dry-cleaning mechanism (https://encryptedtbn0.gstatic.com/images?q=tbn:ANd9GcQUZtuUnDGI4BccziaKrzJ7Bap9E-i5vvoq2VI1mCqmlUYYRVvCbyP6Wet5IQZrFEsxx30&usqp=CAU)

[1.4] Figure 5. Image of Electro repulsion method mechanism
(https://news.mit.edu/sites/default/files/images/202203/MIT-Cleaning-Solar-01-press.jpg)

[1.5] Figure 13. Clean Panel
(https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.researchgate.net%2Ffigure%2FSolar-panel-fixed-on-building-roof-with-30-o-inclination-without-tracker-system-The_fig4_326878893&psig=AOvVaw1ZX7VVi0ZWHe58bF3Xohkn&ust=1671170437714000&source=images&cd=vfe&ved=0CBAQjRxqFwoTCNif6qr8-vsCFQAAAAAdAAAAABAD)

[1.6] Figure 14. light Dirty Panel
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[1.7] Figure 15. Heavy Dirty Panel
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