Semi-Automatic Solar Panel Cleaning System

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the degree of

B.Tech
In
Electrical Engineering

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DECLARATION

We hereby declare that the thesis entitled **“Semi-Automatic Solar Panel Cleaning System”** submitted by us, for the award of the degree of Bachelor of Technology to GEC, Khagaria is a record of bonafide work done under the supervision of **Mr. Bijay Kumar Singh.**

We further declare that the work reported in this thesis has not been submitted and will not be submitted, either in part or in full, for the award of any other degree or diploma in this institute.

Place: Khagaria

Date: 31.05.2025

Signature of the Candidate:

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We express our sincere thanks to the project review committee,Department of Electrical Engineering, Government Engineering College Khagaria,for their suggestions throughout the project.

Finally, We thank our parents and friends who indirectly involved and helped us to complete the project.

Name:
Reg. No:

CERTIFICATE

This is to certify that the thesis entitled **"Semi-Automatic Solar Pannel Cleaning System"** submitted by **Rakhi Kumari** (22103154929),**Bharti Kumari** (22103154930), **Nikita Kumari** (22103154931), **Prabhash Kumar** (22103154932), **Chandani Kumari** (22103154934), and **Gyanendra Kumar** (22103154936), College of Electrical Engineering, GEC, Khagaria, for the award of the degree of Bachelor of Technology in Electrical Engineering, is a record of bona fide work carried out by them under my supervision, as per the GEC code of academic and research ethics.

The contents of this report have not been submitted and will not be submitted either in part or in full, for the award of any other degree or diploma in this institute. The thesis fulfills the requirements and regulations of the University and in my opinion meets the necessary standards for submission.

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ABSTRACT

This project presents an innovative Semi-Automatic Solar Panel Cleaning System designed to enhance the efficiency and lifespan of solar panels by maintaining their cleanliness without manual intervention. Solar panels are often subjected to dust, debris, and other contaminants that accumulate over time, reducing their ability to absorb sunlight and generate power effectively. Traditional cleaning methods can be labour-intensive and costly, especially in remote or large installations. The proposed solution automates the cleaning process using a simple, cost-effective mechanism controlled by an Arduino UNO microcontroller.

The system includes a low-speed 10 RPM gear motor and a wiper blade assembly that gently sweeps across the solar panel surface, removing dirt and dust particles. A water pump is integrated into the system to spray a controlled amount of water onto the panel surface, aiding in the removal of stubborn contaminants. The water is delivered through a pipe connected to the pump, providing an even distribution along the panel's surface. The electrical components, including the Arduino UNO, are powered by a 5V voltage regulator (LM7805), which ensures stable operation, and the overall power supply is managed by a transformer, capacitors, and diodes to ensure safe and efficient energy delivery.

The Arduino UNO is programmed to activate the motor and water pump at preset intervals, which can be customized based on the environment and dust conditions. The 10 RPM motor ensures slow and thorough cleaning, while the wiper blade, mounted securely on the motor, effectively sweeps away particles without damaging the panel's surface. This autonomous system reduces the need for manual labour, saves time, and prevents efficiency loss due to dirt accumulation, ultimately enhancing the energy output of the solar panels. This solution is ideal for large solar farms, residential rooftop solar panels, and installations in areas with high dust levels, offering a sustainable, maintenance-free cleaning solution that maximizes solar power generation efficiency.

CONTENTS

1 INTRODUCTION

Solar energy is one of the most promising sources of renewable energy, offering a sustainable solution to meet the world's growing energy demands while reducing dependence on fossil fuels. Solar panels, or photovoltaic (PV) modules, play a crucial role in capturing sunlight and converting it into usable electrical energy. However, their efficiency is often compromised by environmental factors, such as dust, dirt, bird droppings, and other debris, which accumulate on the surface over time. This buildup of contaminants obstructs sunlight from reaching the solar cells, leading to a significant reduction in energy output. Research shows that uncleaned solar panels can experience up to a 30% drop in efficiency, highlighting the need for regular maintenance.

Traditionally, solar panel cleaning is done manually, a process that can be both labour-intensive and costly, especially for large-scale installations or panels located in hard-to-reach areas. This challenge has sparked interest in developing automated cleaning systems that operate autonomously and ensure solar panels remain clean, thus maximizing energy generation.

The Semi-Automatic Solar Panel Cleaning System described in this project is a simple, efficient, and cost-effective solution to address this issue. Using a combination of mechanical and electronic components, the system automates the cleaning process, utilizing a wiper blade mechanism and water pump to remove dust and debris from the surface of solar panels. At the core of this system is an Arduino UNO microcontroller, which controls the timing and operation of a 10 RPM gear motor attached to the wiper blade, as well as a water pump to apply a gentle water spray. Additional components, including a transformer, diode, capacitors, and a 5V voltage regulator (LM7805), are used to manage and stabilize the power supply.

This project aims to provide an accessible and effective cleaning solution that is suitable for residential, commercial, and industrial solar installations. By automating the cleaning process, this system ensures consistent energy production, reduces the need for manual cleaning, and contributes to the overall reliability and efficiency of solar power systems.

1.1 Objective

The objective of this project is to design and implement Semi-Automatic Solar Panel Cleaning System that enhances the efficiency and lifespan of solar panels by removing dust and debris.

minutes for testing purposes, but this can be adapted based on the solar panel's operational environment.

- The code ensures that the motor activates first, moving the wiper blade across the panel, followed by the water pump, which sprays water at controlled intervals to assist the cleaning process.

1.1.2 Integration and Testing of Components:

- The motor and wiper blade assembly are tested independently to ensure smooth movement without causing scratches or damage to the solar panel. Adjustments to the motor’s mounting and the angle of the wiper blade may be necessary to optimize contact with the panel’s surface.
- The water pump and pipe are tested to confirm even water distribution across the panel. The pipe positioning is adjusted as needed to achieve an optimal spray pattern, and the water pressure is controlled to avoid excessive water use.
- The power supply circuit is assembled and tested to verify a steady 5V output. Any instability or voltage drops are addressed by adjusting capacitor values or diode placements.

1.1.3 System Integration and Testing:

- Once each component is tested individually, they are integrated into a single system, with wiring organized to reduce clutter and prevent interference.
- The full cleaning cycle is tested repeatedly to evaluate the system’s performance in terms of timing, water usage, and cleaning efficiency. Adjustments are made to the Arduino code, water spray intervals, or motor operation as needed.
- Durability tests are conducted by running the system continuously to ensure all components withstand repeated use and environmental factors, such as exposure to water.

1.1.4 Optimization and Final Adjustments:

- Based on initial testing, fine-tuning of the cleaning cycle duration, motor speed, and water pump intervals is performed to balance cleaning efficiency and resource usage.

- The prototype is reviewed for improvements, such as incorporating sensors to detect dust levels or adding a battery backup for off-grid functionality, to enhance the system's autonomy.

1.2 Aim

The aim of the Semi-Automatic Solar Panel Cleaning System project is to develop an efficient, autonomous solution that enhances the energy production and lifespan of solar panels by maintaining a clean surface free from dust, dirt, and other contaminants. By automating the cleaning process with a controlled mechanism involving a wiper blade, water pump, and microcontroller, this project seeks to eliminate the need for manual cleaning, reduce maintenance costs, and optimize solar panel performance in various environments. Ultimately, the goal is to maximize the solar energy output and operational efficiency of solar installations, especially in areas where regular manual cleaning is challenging or costly.

2 LITERATURE REVIEW

This literature review aims to synthesize existing literature spanning various topics, including security, privacy, communication protocols, energy efficiency, and interoperability, among others. By critically analysing a diverse range of research papers, review articles, and scholarly publications, this review seeks to identify emerging trends, gaps in knowledge, and areas for future research.

2.1 "Effect of Dust on the Performance of Solar Photovoltaic Modules"

- *by M.S. Hegazy, F. J. Husain, and W. A. Ghoneim*

This study examines how dust accumulation on solar panel surfaces leads to reduced energy output, focusing on the effects of particle size, type, and thickness. The findings emphasize the need for regular cleaning, supporting the use of automated systems to mitigate energy losses.

2.2 "Impact of Dust Accumulation on Solar Photovoltaic Performance: Experimental Analysis"

- *by R. S. Kaldellis, A. Fragos, and N. Kavadias*

The paper provides experimental data on the significant decline in solar panel efficiency due to dust, with reductions of up to 30% over time. This research underlines the necessity of periodic cleaning mechanisms to maintain optimal panel performance, particularly in dusty regions.

2.3 "Automated Cleaning System for Solar Panels Using Arduino"

- *by S. Thomas, D. Singh, and A. Kumar*

This paper presents an Arduino-controlled cleaning system that uses motorized wipers and water sprayers. The authors detail the design process and demonstrate how automated cleaning can restore energy output while reducing maintenance costs.

2.4 "Design and Development of an Autonomous Solar Panel Cleaning System”.

- *by J. Kim, H. J. Chang, and C. Lim*

This research introduces an autonomous cleaning device that uses sensors to detect dust levels and activate a cleaning mechanism. The study explores the potential for intelligent cleaning systems that operate only when needed, optimizing resource usage and improving efficiency.

2.5 "Development of Arduino-Based AC Power Monitoring and Control System"

- *by M. Mani and R. Pillai*

The authors investigate the impact of environmental factors, including dust and humidity, on solar panel efficiency. They provide insights into different types of debris and their effects on panels, stressing the importance of automated cleaning systems in variable climates.

2.6 "Improving Solar PV Efficiency Through Automated Water-Based Cleaning Systems"

- *by L. J. Mejia, F. Torres, and R. Martinez*

This paper focuses on the use of water-based cleaning systems for solar panels, analysing water pressure, distribution, and usage. It offers valuable insights into water conservation and efficiency, which are relevant for designing an eco-friendly cleaning mechanism.

2.7 "Solar Panel Cleaning Methods and Their Economic Impact"

- *by P. K. Patra, R. K. Singh, and S. R. Mishra*

This study compares manual and automated cleaning methods, assessing costs, labour requirements, and efficiency gains. The economic analysis supports automated cleaning as a cost-effective, labour-saving alternative for maintaining large-scale solar farms.

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2.8 "Design and Implementation of Microcontroller-Based Cleaning System for Solar Panels"

- *by M. Rahman, A. Habib, and S. Ahmed*

The paper presents a microcontroller-based cleaning system that uses sensors to trigger cleaning cycles. The study highlights how automation and sensor integration can optimize cleaning frequency, resulting in greater energy output with minimal water and power usage.

3 SOFTWARE COMPONENTS

3.1 Arduino IDE

The ATMega328p microcontroller IC with Arduino bootloader makes a lot of work easier in this project as Arduino code is written in C++ with an addition of special methods and functions, which we'll mention later on. C++ is a human-readable programming language. When you create a 'sketch' (the name given to Arduino code files), it is processed and compiled to machine language.

The Arduino Integrated Development Environment (IDE) is the main text editing program used for Arduino programming. It is where you'll be typing up your code before uploading it to the board you want to program. Arduino code is referred to as sketches.

Figure 3.1: Arduino IDE

4 HARDWARE COMPONENTS

4.1 Arduino UNO:

The Arduino Uno is a microcontroller board based on the ATmega328.It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header, and a reset button. Arduino board designs use a variety of microprocessors and controllers.

The boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards or breadboards (shields) and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers.

The microcontrollers are typically programmed using a dialect of features from the programming languages C and C++. In addition to using traditional compiler toolchains the Arduino project provides an integrated development environment (IDE) based on the Processing language project.

Most Arduino boards consist of an Atmel 8-bit AVR microcontroller (Atmega8, Atmega168, Atmega328, Atmega1280, Atmega2560) with varying amounts of flash memory, pins, and features. The 32-bit Arduino Due, based on the Atmel SAM3X8E was introduced in 2012. The boards use single or double-row pins or female headers that facilitate connections for programming and incorporation into other circuits. These may connect with add-on modules termed shields.

Multiple and possibly stacked shields may be individually addressable via an I^2C serial bus. Most boards include a 5V linear regulator and a 16 MHz crystal oscillator or ceramic resonator. Some designs, such as the Lilypad, run at 8 MHz and dispense with the onboard voltage regulator due to specific form-factor restrictions.

Arduino microcontrollers are pre-programmed with a boot loader that simplifies uploading of programs to the on-chip flash memory. The default bootloader of the Arduino UNO is the Opti boot bootloader Boards are loaded with program code via a serial connection to another computer.

Some serial Arduino boards contain a level shifter circuit to convert between RS-232 logic levels and transistor-transistor logic (TTL) level signals. Current Arduino boards are programmed via Universal Serial Bus (USB), implemented using USB-to-serial adapter chips such as the FTDI FT232. Some boards, such as later-model Uno boards, substitute the FTDI chip with a separate AVR chip containing USB-to-serial firmware, which is reprogrammable via its own ICSP header.

Other variants, such as the Arduino Mini and the unofficial Boarduino, use a detachable USB-to-serial adapter board or cable, Bluetooth, or other methods. When used with traditional microcontroller tools, instead of the Arduino IDE, standard AVR in-system programming (ISP) programming is used.

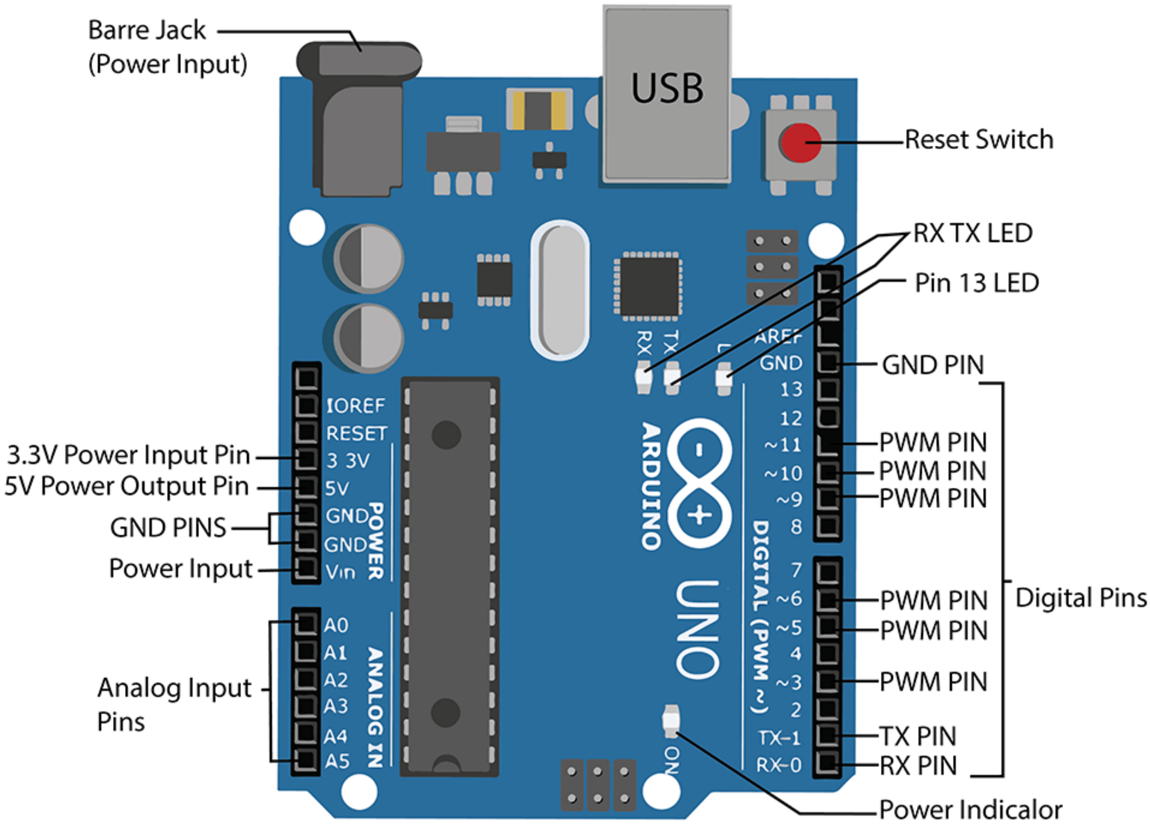

Figure 4.11: Diagram of Arduino Uno

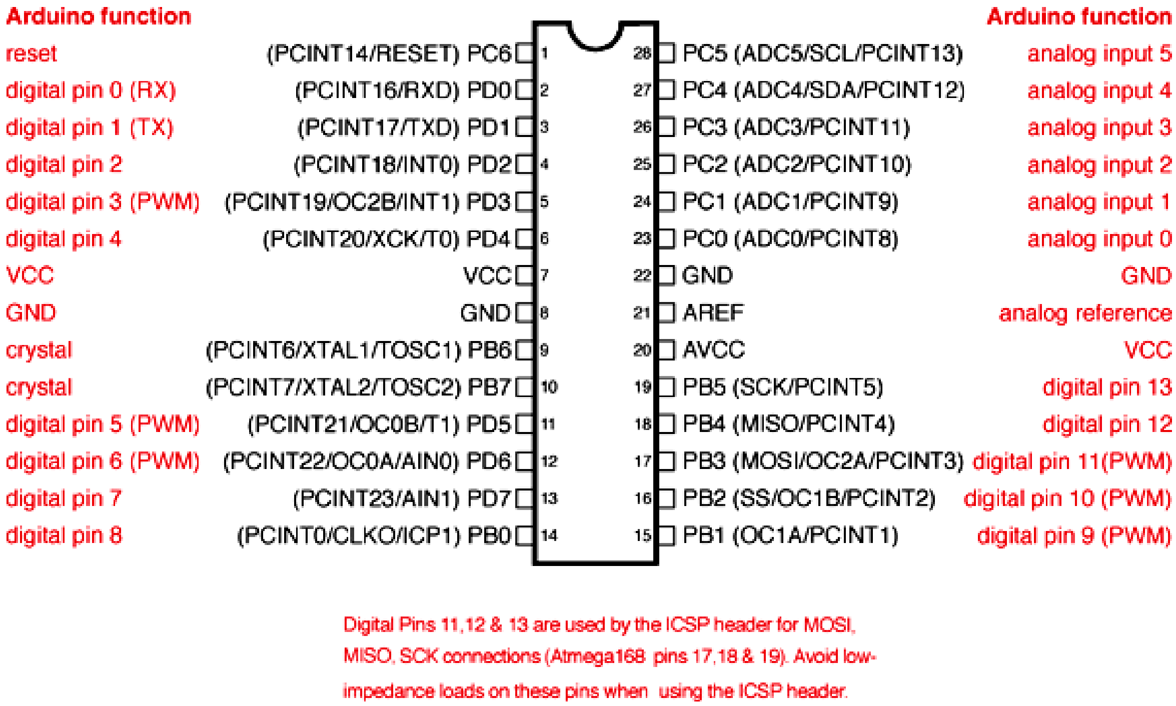

Figure 4.12 : PIN Layout of Arduino Uno

Vin: The input voltage or Vin to the Arduino while it is using an exterior power supply opposite to volts from the connection of USB or else RPS (regulated power supply). By using this pin, one can supply the voltage.

5Volts: The RPS can be used to give the power supply to the microcontroller as well as components which are used on the Arduino board. This can approach from the input voltage through a regulator.

3V3: A 3.3 supply voltage can be generated with the onboard regulator, and the highest draw current will be 50 mA.

GND: GND (ground) pins

Memory:

The memory of an ATmega328 microcontroller includes 32 KB and 0.5 KB memory is utilized for the Boot loader), and also it includes SRAM-2 KB as well as EEPROM-1KB.

Input and Output:

We know that an arguing Uno R3 includes 14-digital pins which can be used as an input otherwise output by using the functions like pinMode(), digitalRead(), and digitalWrite(). These pins can operate with 5V, and every digital pin can give or receive 20mA, & includes a 20k to 50k ohm pull up resistor. The maximum current on any pin is 40mA which cannot surpass for avoiding the microcontroller from the damage. Additionally, some of the pins of an Arduino include specific functions.

Serial Pins:

The serial pins of an Arduino board are TX (1) and RX (0) pins and these pins can be used to transfer the TTL serial data. The connection of these pins can be done with the equivalent pins of the ATmega8 U2 USB to TTL chip.

External Interrupt Pins:

The external interrupt pins of the board are 2 & 3, and these pins can be arranged to activate an interrupt on a rising otherwise falling edge, a low-value otherwise a modify in value.

PWM Pins:

The PWM pins of an Arduino are 3, 5, 6, 9, 10, & 11, and gives an output of an 8-bit PWM with the function analog Write ().

SPI (Serial Peripheral Interface) Pins:

The SPI pins are 10, 11, 12, 13 namely SS, MOSI, MISO, SCK, and these will maintain the SPI communication with the help of the SPI library.

LED Pin:

An arguing board is inbuilt with a LED using digital pin-13. Whenever the digital pin is high, the LED will glow otherwise it will not glow.

TWI (2-Wire Interface) Pins:

The TWI pins are SDA or A4, & SCL or A5, which can support the communication of TWI with the help of Wire library.

AREF (Analog Reference) Pin:

An analog reference pin is the reference voltage to the inputs of an analog i/ps using the function like analog Reference().

Reset (RST) Pin:

This pin brings a low line for resetting the microcontroller, and it is very useful for using an RST button toward shields which can block the one over the Arduino R3 board.

Communication:

The communication protocols of an Arduino Uno include SPI, I2C, and UART serial communication.

UART:

An Arduino Uno uses the two functions like the transmitter digital pin1 and the receiver digital pin0. These pins are mainly used in UART TTL serial communication.

I2C:

An Arduino UNO board employs SDA pin otherwise A4 pin & A5 pin otherwise SCL pin is used for I2C communication with wire library. In this, both the SCL and SDA are CLK signal and data signal.

SPI Pins:

The SPI communication includes MOSI, MISO, and SCK.

MOSI (Pin11):

This is the master out slave in the pin, used to transmit the data to the devices

MISO (Pin12):

This pin is a serial CLK, and the CLK pulse will synchronize the transmission of which is produced by the master.

SCK (Pin13):

The CLK pulse synchronizes data transmission that is generated by the master. Equivalent pins with the SPI library is employed for the communication of SPI. ICSP (in-circuit serial programming) headers can be utilized for programming ATmega microcontroller directly with the boot loader.

4.2 Solar Panel:

The solar panel is the core component of the system, responsible for converting sunlight into electrical energy through the photovoltaic (PV) effect. In this project, the solar panel is used both as a power source for the system and as the target for cleaning. Solar panels are made up of numerous photovoltaic cells that absorb sunlight and generate direct current (DC) electricity. These cells are typically made from silicon, which is efficient at converting light energy into electrical energy. The energy produced by the panel powers the system's motor, water pump, and Arduino microcontroller, which makes the system autonomous without requiring an external power source.

As the solar panel operates, its surface collects dust, dirt, and debris, which can obstruct the sunlight and decrease its efficiency. In areas with high dust accumulation or pollution, this can lead to significant power loss, sometimes reducing efficiency by as much as 20-30%. The purpose of the automated cleaning system is to ensure that the panel remains clean, allowing it to function at its maximum efficiency. The cleanliness of the solar panel is directly linked to the overall performance and return on investment of the solar energy system, making the cleaning process a critical factor in optimizing energy output. The solar panel's surface is usually made of tempered glass to withstand environmental factors such as rain, wind, and UV radiation, ensuring durability under diverse conditions.

The selection of the solar panel for the prototype depends on the scale and intended use of the project. In a testing scenario, smaller solar panels are often used to evaluate the effectiveness of the cleaning system before applying it to larger commercial or industrial solar farms. The materials and design of the panel are chosen to complement the cleaning system, ensuring that the wiper blade can sweep effectively across the surface without causing damage. Additionally, solar panels are designed to be resistant to scratches and wear, which helps protect them during the cleaning process. Regular maintenance of the panel's surface is essential to maintaining consistent energy generation, and an automated system ensures that cleaning is done at appropriate intervals.

In a larger commercial or industrial application, the Semi-Automatic cleaning system could be scaled up to accommodate larger, more complex solar panel arrays. Such installations often face greater challenges with dust accumulation, especially in regions where sandstorms or high levels of pollution are common. Therefore, the cleaning system must be efficient enough to handle the size and surface area of multiple panels, ensuring that the energy loss due to dust buildup is minimized across the entire installation.

Figure 4.2 : Solar Panel

4.3 10 RPM Gear Motor:

The 10 RPM gear motor is a critical component for providing the mechanical movement necessary to drive the wiper blade across the surface of the solar panel. Gear motors are typically used in applications requiring low-speed, high-torque output. The gear mechanism reduces the speed of the motor while increasing the torque, making it ideal for tasks such as sweeping or pushing, where slow, steady motion is needed without excessive force. In this project, the 10 RPM gear motor is selected for its ability to move the wiper blade gently across the panel without causing damage, while also ensuring that the panel is cleaned thoroughly.

The gear motor is connected to the wiper blade assembly, with the motor's shaft providing the rotational force necessary to drive the blade. A slower RPM (10 RPM) is chosen to ensure that the wiper does not move too quickly across the panel, allowing for a more thorough cleaning action that can effectively remove dust and dirt. This speed is optimal for cleaning purposes, as it avoids the risk of the wiper blade skipping or missing areas, which could result in uneven cleaning. Additionally, slower movement prevents the potential for scratches or damage to the surface of the solar panel, which could be a concern if the wiper were moving at higher speeds.

One key advantage of using a 10 RPM gear motor is its energy efficiency. As the motor operates at a relatively low speed, it draws less current, which helps in conserving the power generated by the solar panel. This allows the system to run for extended periods without drawing significant amounts of energy from the panel. The motor's ability to function efficiently on the solar panel's power supply aligns with the goal of creating an autonomous cleaning system that is self-sufficient and does not require additional external energy sources.

In terms of control, the motor's operation is managed by the Arduino microcontroller, which sends signals to turn the motor on and off at the appropriate times during the cleaning cycle. The motor's speed is well-suited to cleaning operations, offering a balance between effective dirt removal and gentle handling of the panel surface. The gear motor's simplicity and durability make it a suitable choice for automated systems that need to operate over extended periods, ensuring long-term functionality without the need for frequent maintenance.

Figure 4.3: 10 RPM Gear Motor

4.4 Wiper Blade:

The wiper blade is the mechanical component that physically removes dust and debris from the surface of the solar panel. It is typically made from flexible, non-abrasive materials such as rubber or silicone to ensure that it does not scratch or damage the tempered glass surface of the solar panel. The wiper blade is mounted to the motor's shaft via a simple arm mechanism that allows it to move across the solar panel in a sweeping motion, much like a windshield wiper on a car. The material choice for the blade is critical, as it needs to be both soft enough to prevent damage and durable enough to withstand repeated use.

The design of the wiper blade ensures full coverage of the solar panel during each cleaning cycle. Depending on the size of the panel, the blade may be wide enough to clean the panel in a single pass or may need to perform multiple passes to cover the entire surface. The blade's gentle, sweeping motion helps lift and remove dirt, dust, and other debris that may have accumulated on the panel. For optimal cleaning, the wiper blade is designed to follow the shape of the panel, ensuring it does not miss any areas, including the corners or edges where dirt may accumulate more readily.

Figure 4.4 : Wiper Blades

A key consideration when designing the wiper blade mechanism is the balance between pressure and movement. If the blade applies too much force to the panel, it could risk causing scratches or microfractures in the glass. On the other hand, too little pressure could result in ineffective cleaning. The wiper blade is typically adjusted to make light, uniform contact with the solar panel surface, ensuring that it picks up dirt without exerting excess pressure.

The wiper blade's effectiveness is enhanced when used in combination with the water pump, which wets the panel's surface before the blade moves across it. This water helps loosen stubborn dirt and ensures a smoother cleaning process. Additionally, the wiper blade should be easy to replace or maintain, as over time, the blade material may wear out due to contact with dust and water. Regular maintenance and periodic replacement of the blade will ensure that the cleaning system continues to operate at optimal efficiency.

4.5 Water Pump:

The water pump is an essential part of the cleaning system, as it helps apply water to the surface of the solar panel to loosen dirt and dust before the wiper blade moves across it. Water-based cleaning is highly effective for solar panels, especially when dealing with stubborn dirt or grime that a dry wiper blade alone cannot remove. The pump is typically designed to be compact and capable of handling low water pressure, which is ideal for this application. The water pump can be powered directly from the solar panel’s electrical output, further enhancing the system's autonomy.

The pump is connected to a water reservoir and uses pipes to deliver water to the panel. It is important for the pump to distribute water evenly across the panel to ensure that the surface is adequately wet before the wiper blade begins its cleaning cycle. Proper water distribution ensures that the dirt is softened and loosened, making it easier for the wiper blade to push it off the panel. By adding moisture, the pump helps reduce the friction between the wiper blade and the panel, which further protects the surface from potential damage.

Figure 4.5 : Water Pump

The water pump is controlled by the Arduino, which activates it at predetermined intervals during the cleaning process. The pump can be designed with a flow control valve or nozzle to regulate the amount of water released, ensuring that only a sufficient amount is used to clean the surface without wasting water. This feature is important in areas where water conservation is a priority.

By incorporating the water pump into the cleaning system, the project achieves a higher level of cleaning efficiency compared to dry cleaning methods. The pump's design must take into account factors like flow rate, water pressure, and durability to ensure it can perform consistently over time. In environments where water availability is limited, it may also be necessary to include a water-saving mechanism to minimize water consumption while still achieving effective cleaning results.

4.6 Pipe

The pipes serve an essential role in the transportation of water to and from the various components of the system. The pipes are used to carry water from the pump to the solar panel, where the water is distributed evenly across the surface to assist with cleaning. The design of the pipes is important, as they must be flexible enough to be positioned and routed efficiently across the panel without causing obstruction or damage. Depending on the system's size, pipes can be made from materials like plastic or rubber, which are durable and resistant to weathering.

The pipes must be placed in such a way that they allow for uniform water distribution across the solar panel's surface. This ensures that the cleaning process is thorough, and every part of the panel is wetted before the wiper blade makes its pass. Depending on the water distribution mechanism, the pipes may include nozzles or flow restrictors to regulate the amount of water dispensed at a time, ensuring optimal water usage without waste. The pipe design must also consider factors such as ease of maintenance and the possibility of clogging, which could hinder the cleaning process.

Figure 4.6 : Pipe

4.7 Electrolytic Capacitor

The capacitor is a component which has the ability or "capacity" to store energy in the form of an electrical charge producing a potential difference (Static Voltage) across its plates, much like a small rechargeable battery.

There are many different kinds of capacitors available from very small capacitor beads used in resonance circuits to large power factor correction capacitors, but they all do the same thing, they store charge.

In its basic form, a capacitor consists of two or more parallel conductive (metal) plates which are not connected or touching each other but are electrically separated either by air or by some form of a good insulating material such as waxed paper, mica, ceramic, plastic or some form of a liquid gel as used in electrolytic capacitors. The insulating layer between a capacitors plate is commonly called the Dielectric.

Figure 4.7 : A Typical Capacitor

Due to this insulating layer, DC current cannot flow through the capacitor as it blocks it allowing instead a voltage to be present across the plates in the form of an electrical charge.

4.8 Wire Lead

The wire leads are used to connect all the electronic components, ensuring that power and signals are delivered from the power source to the Arduino, motor, and water pump. Wire leads are chosen based on the current requirements of the system, ensuring that they are of adequate thickness to handle the electrical load without overheating or causing signal loss. The wires are insulated to prevent accidental short circuits and are routed to minimize exposure to external elements, protecting them from weather-related wear and tear.

Proper wiring is essential for ensuring that the system operates efficiently and safely. The wiring needs to be routed cleanly and securely to avoid damage or interference with the system's operation. In the case of the prototype, wire leads should be carefully managed to ensure they do not interfere with the wiper blade’s movement or water distribution. Clear organization of the wiring not only improves the safety and reliability of the system but also makes it easier to troubleshoot and maintain the components over time.

Figure 4.8 : Wire Lead

4.9 12-0-12 Transformer

Transformers work on the principle of mutual induction. A changing magnetic field in one loop of wire induces an electromotive force (EMF) in an adjacent loop of wire, inductively coupled to the first. In very basic terms, a transformer consists of two coils of wire with high mutual inductance. These coils are electrically separated while they share a common magnetic circuit.

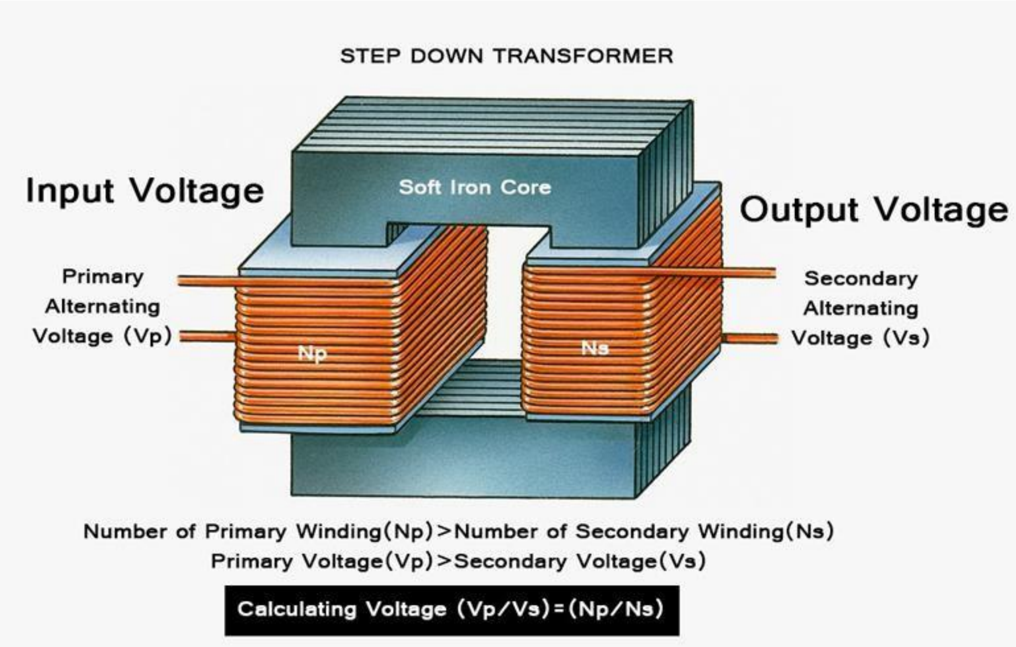

Figure 4.91 : Transformer

- A step-down transformer has more primary windings than the secondary side.

For a step-down transformer, the second coil has fewer windings than the first, allowing for a decrease in voltage in the exiting electrical stream.

The primary winding, which is the first set of coils, connects to an alternating-current voltage source, or primary voltage inflow. The secondary coil connects to the load, or secondary voltage outflow, distributing the electrical power away from the transformer.

A Step-down voltage of 230 V AC to 12V transformer with a maximum current of 1Amp.

Specifications:

“voltage: - 2 x 12V

current: -1 x 1000mA

power rated: - 24VA”

Figure 4.92 : Transformer

The output from this transformer will be 12V AC supply which will be passed through a rectifier circuit to convert this AC supply to DC supply.

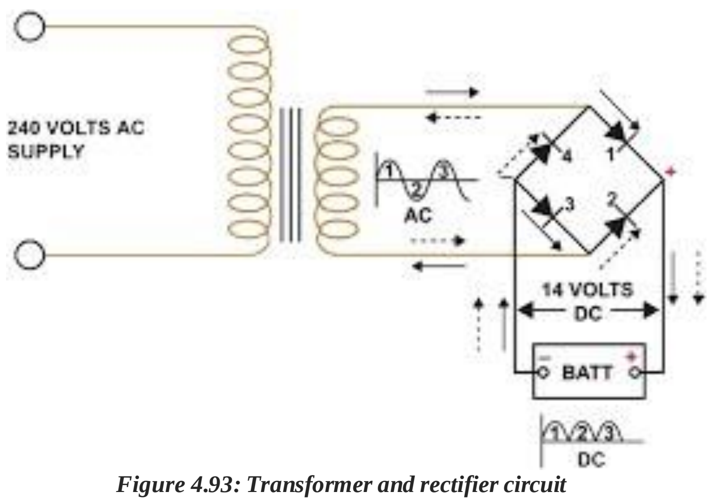

Figure 4.93: Transformer and rectifier circuit

4.10 Diodes

A diode is a semiconductor device that essentially acts as a one-way switch for current. It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction.

Diodes are also known as rectifiers because they change alternating current (ac) into pulsating direct current (dc). Diodes are rated according to their type, voltage, and current capacity.

Diodes have polarity, determined by an anode (positive lead) and cathode (negative lead). Most diodes allow current to flow only when positive voltage is applied to the anode. A variety of diode configurations are displayed in this graphic:

Figure 4.10 .1 : Diodes

Diodes are available in various configurations. From left metal case, stud mount, plastic case with band, plastic case with chamfer, glass case.

When a diode allows current flow, it is forward-biased. When a diode is reverse-biased, it acts as an insulator and does not permit current to flow.

The diode symbol's arrow points against the direction of electron flow. Reason: Engineers conceived the symbol, and their schematics show current flowing from the positive (+) side of the voltage source to the negative (-). It's the same convention used for semiconductor symbols that include arrows—the arrow points in the permitted direction of "conventional" flow, and against the permitted direction of electron flow.

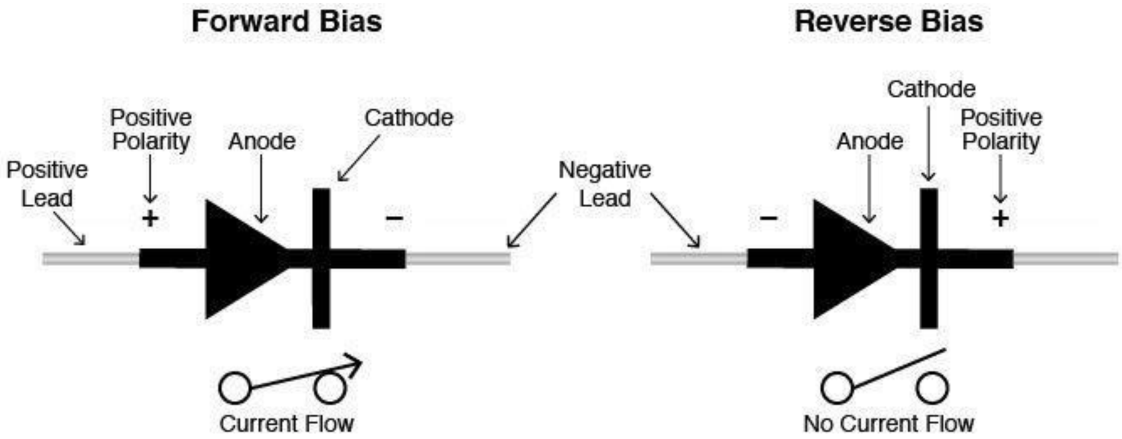

Figure 4.10.2 : Current Flow in diode

A digital multimeter's diode test diode produces a small voltage between the test leads enough to forward-bias a diode junction. Normal voltage drop is 0.5 V to 0.8 V. The forward- biased resistance of a good diode should range from 1000 ohms to 10 ohms. When reverse- biased, a digital multimeter's display will read OL (which indicates very high resistance).

Diodes are assigned current ratings. If the rating is exceeded and the diode fails, it may short and either a) allow current to flow in both directions or b) halt current from flowing in either direction.

4.11 5V Voltage Regulator

A voltage regulator IC maintains the output voltage at a constant value. 7805 IC, a member of 78xx series of fixed linear voltage regulators used to maintain such fluctuations, is a popular voltage regulator integrated circuit (IC). The xx in 78xx indicates the output voltage it provides. 7805 IC provides +5 volts regulated power supply with provisions to add a heat sink. A 7805 IC's input voltage range can vary from 7 Volts to 35 Volts.

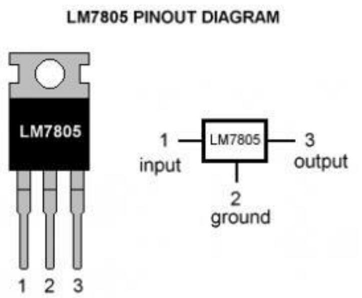

Figure 4.11.1 : Pinout of LM7805

1	INPUT	Input voltage (7V-35V)	In this pin of the IC positive unregulated voltage is given in regulation.
2	GROUND	Ground (0V)	In this pin where the ground is given. This pin is neutral for equally the input and output.
3	OUTPUT	Regulated output; 5V (4.8V-5.2V)	The output of the regulated 5V volt is taken out at this pin of the IC regulator

As you may have noticed, there is a significant difference between the input voltage & the output voltage of the voltage regulator. This difference between the input and output voltage is released as heat. The greater the difference between the input and output voltage, the more the heat generated. If the regulator does not have a heat sink to dissipate this heat, it can get destroyed and malfunction. Hence, it is advisable to limit the voltage to a maximum of 2-3 volts above the output voltage. So, we now have 2 options. Either design your circuit so that the input voltage going into the regulator is limited to 2-3 volts above the output regulated voltage or place an appropriate heatsink, that can efficiently dissipate heat.

LM7805 is applied in a wide range of circuits:

- Fixed-Output Regulator
- Positive Regulator in Negative Configuration
- Adjustable Output Regulator
- Currtent Regulator
- Regulated Dual-Supply
- Output Polarity-Reversal-Protection Circuit
- Reverse bias projection Circuit

If differences between the input and output voltages are not well managed, LM7805 can overheat, which may result in malfunctioning. Solutions Include:

- Limiting input voltage to 2-3 volts above the output regulated voltage
- Placing a heat sink in the circuit to dissipate heat solutions.

If your voltage regulator is situated more than 25cm (10 inches) from the power supply, capacitors are needed to filter residual AC noise. Voltage regulators work efficiently on a clean DC signal being fed. The bypass capacitors help reduce AC ripple. Essentially, they short AC noise from the voltage signal and allow only DC voltage into the regulator. The two capacitors are not necessarily required and can be omitted if you are not concerned about line noise.

However, for a mobile phone charger or logic assessment, you require a nice clean DC line. Capacitors will be beneficial in this case as they are good at maximizing voltage regulation. The values of capacitors can also be changed slightly.

5 DESIGN AND IMPLEMENTATION

5.1 Block Diagram

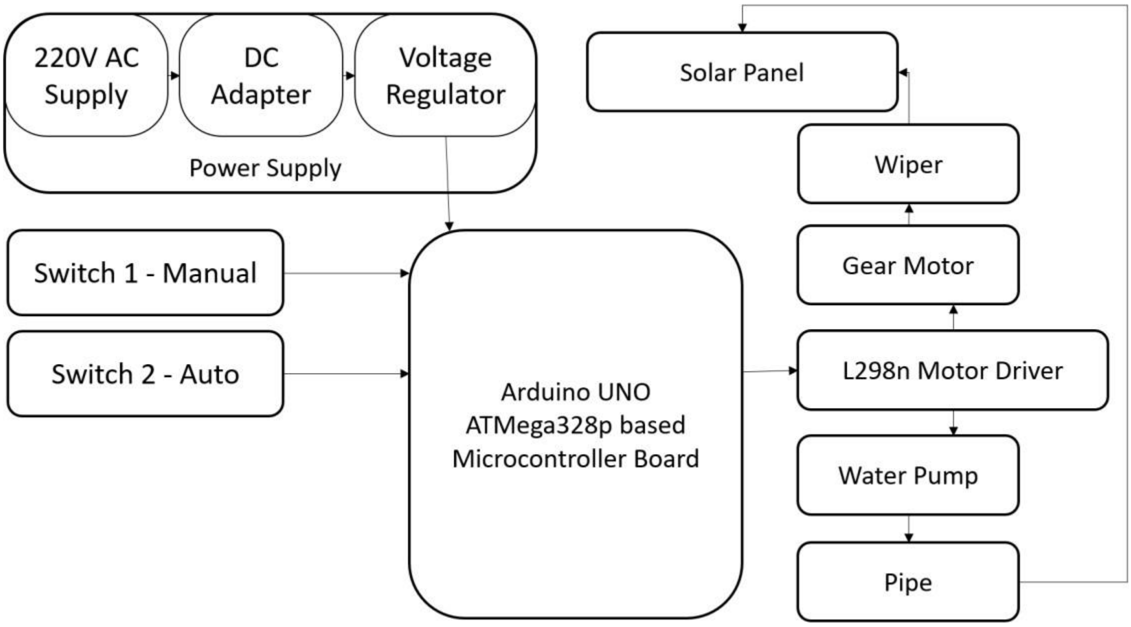

Figure 5 .1: Block diagram of the System

5.2 Circuit Diagram

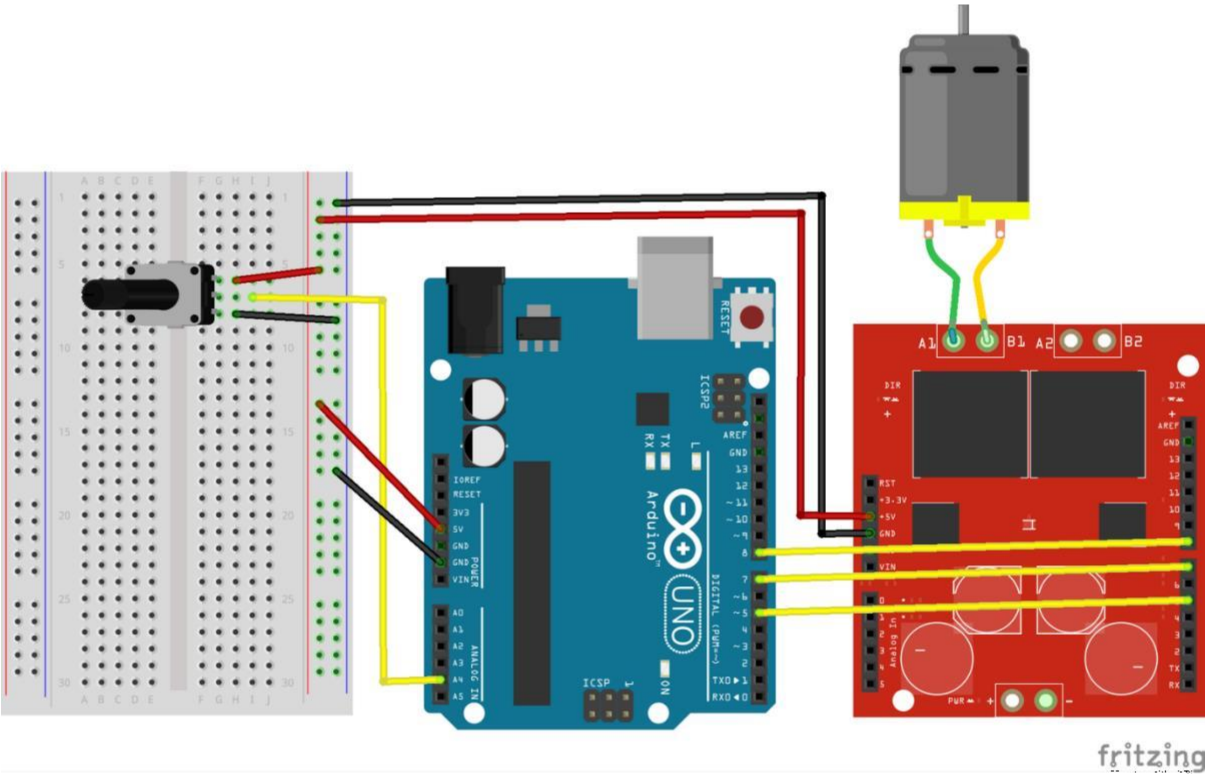

Figure 5.2 : Circuit Diagram of The System

5.3 Code for Arduino IDE

```
#define pump 9       //Pin for Water Pump

#define wpr1 10      //Pin for Gear Motor

#define wpr2 11      //Pin for Gear Motor

#define swtch 8      //Arduino Pin to GND


#define SPEED 100     //Speed of wiper between 0 - 255

#define ANGLE 3000    //Timer to reverse the Direction

#define WATER 500     //Timer to keep the water runing

#define TIMES 2       //Number of times wiper clean it
```

```
void setup() {
  Serial.begin(9600);
  pinMode(pump, OUTPUT);
  pinMode(wpr1, OUTPUT);
  pinMode(wpr2, OUTPUT);
  pinMode(swtch, INPUT);
  digitalWrite(pump, LOW);
  analogWrite(wpr1, 0);
  analogWrite(wpr2, 0);
}

void loop() {
  if (digitalRead(9)) {
    for (int i = 0 ; i < TIMES; i++) {
      digitalWrite(pump, HIGH);
      delay(WATER);
      digitalWrite(pump, LOW);
      delay(300);
      analogWrite(wpr1, SPEED);
      analogWrite(wpr2, 0);
      delay(ANGLE);
      analogWrite(wpr1, 0);
      analogWrite(wpr2, SPEED);
      delay(ANGLE);
```

```
      delay(300);
    }
  }
}
```

5.4 Major tasks Involved.

The development of an Semi-Automatic solar panel cleaning system involves several major tasks, each crucial for ensuring the system operates efficiently and effectively. These tasks range from initial design and component selection to implementation, testing, and maintenance. Below is a detailed breakdown of the major tasks involved:

5.4.1 System Design and Component Selection

The first step in the development of the Semi-Automatic solar panel cleaning system is to design the system architecture and select the appropriate components. This includes:

- **Defining System Requirements:** The first task is to define the system's specific requirements, including the size of the solar panels to be cleaned, the expected environmental conditions (dust levels, climate), and the cleaning frequency. This helps in determining the type of solar panels, motors, and cleaning mechanisms needed.
- **Selecting Components:** Components such as the solar panel, gear motor (10 RPM), wiper blade, water pump, Arduino UNO microcontroller, LM7805 voltage regulator, and supporting components like wires, pipes, and sensors must be selected based on their compatibility, performance, and durability. For example, the choice of a gear motor depends on the required torque and speed for cleaning, while the water pump should be capable of delivering water efficiently without overuse.
- **Circuit Design:** The electrical connections and circuit diagram need to be designed. This includes how the power from the solar panel will be routed through the system, the role of the LM7805 voltage regulator, and how the water pump and motor will be powered and controlled by the Arduino.

5.4.2 Prototyping and Assembly of Components

Once the system design is finalized, the next task is to build the prototype. This task involves the following steps:

- **Mounting the Solar Panel:** The solar panel is mounted securely in a location where it can receive maximum sunlight exposure. In a prototype, this could involve a simple fixed frame or a temporary setup to test the system.
- **Assembling the Wiper Mechanism:** The gear motor is mounted to the wiper arm, and the wiper blade is attached to the arm. This mechanism is designed so that the wiper moves back and forth across the surface of the solar panel, effectively removing dirt and debris.
- **Setting Up the Water Pump:** The water pump is installed and connected to a water reservoir. The pump's output is routed through pipes that lead to the solar panel. The pump is designed to supply water at a low flow rate, ensuring that it does not flood the panel but provides enough moisture to loosen the dirt.
- **Wiring the Electrical System:** Wiring is carried out to connect the Arduino, motor, pump, and other components. The Arduino UNO is connected to the motor driver and pump, with power regulated by the LM7805 voltage regulator. The wiring must be neat and secure, with appropriate insulation to prevent short circuits.

5.4.3 Arduino Programming and System Control

Programming the Arduino is a crucial task that involves writing the code to control the system's actions. The following steps are involved in this process:

- **Motor Control Logic:** The Arduino must be programmed to control the motor's operation. This involves turning the motor on to move the wiper blade across the solar panel at the correct speed (10 RPM). The Arduino may also manage motor direction if bi-directional movement is required to clean the entire surface.
- **Water Pump Control:** The water pump needs to be activated to spray water on the solar panel before the wiper starts cleaning. The timing for activating the water pump is essential to ensure that enough water is dispensed for cleaning but not wasted.
- **Cleaning Cycle Programming:** The system needs to be programmed to operate autonomously, with a defined cleaning cycle that includes turning on the water pump, waiting for a brief period, and then moving the wiper blade. The cycle should be

repeated at set intervals based on the environmental conditions or the level of dust accumulation.

- **Sensor Integration (if applicable):** If sensors are included (e.g., soil moisture sensors or dust sensors), the Arduino can use these inputs to adjust the cleaning cycle dynamically. For example, if a dust sensor detects an accumulation of dust, the system can Semi-Automatically trigger a cleaning cycle.
- **Testing and Debugging:** Once the programming is done, the system needs to be tested and debugged to ensure that all components work as expected. This task may involve troubleshooting any issues related to motor control, water pump timing, or power distribution. Adjustments to the code may be required for optimization.

5.4.4 Testing and Calibration

After assembling and programming the system, comprehensive testing is required to ensure the system performs as intended. This involves:

- **Initial Testing:** The system should be tested in a controlled environment to check the basic functionality, including whether the wiper blade moves correctly, the water pump sprays at the right time, and the Arduino properly controls the components.
- **Adjusting Parameters:** The testing phase may reveal issues such as excessive water usage or the wiper blade moving too fast or too slow. These parameters can be adjusted by modifying the Arduino code or physically adjusting the motor speed.
- **Solar Panel Integration Testing:** The final step is to test the system on an actual solar panel to verify that it effectively removes dust and debris without damaging the panel. The cleaning performance should be evaluated under real conditions, taking into account the dust level, panel size, and environmental factors.
- **Long-Term Testing:** To ensure durability and reliability, long-term testing is essential. This includes evaluating how the system performs over several cleaning cycles, checking for wear and tear on components like the wiper blade, and assessing the impact of environmental factors such as temperature fluctuations or rain on the system's operation.

5.4.5 System Optimization

Once the system is functioning properly, optimization tasks can be carried out to improve efficiency, energy usage, and performance:

- **Energy Efficiency:** The system can be optimized to use minimal energy, ensuring that it operates solely on the power generated by the solar panel. This might involve adjusting the timing of the water pump and motor to minimize energy consumption.
- **Water Conservation:** The amount of water used during cleaning can be optimized by fine-tuning the pump's output or using sensors to determine the exact amount of water needed. This is particularly important in areas where water is scarce.
- **Component Longevity:** The system should be designed to ensure the longevity of components. This includes choosing durable materials for the wiper blade, motor, and pipes, as well as ensuring that the water pump is resistant to corrosion over time.

5.4.6 Deployment and Integration

Once the system has been successfully tested and optimized, the next step is deployment. This includes:

- **Installation on Solar Farms or Rooftops:** The cleaning system must be installed on large-scale solar panel installations or rooftop solar panels. Installation involves securely mounting the cleaning system and ensuring that the wiper mechanism can effectively cover the entire panel surface.
- **Automated Operation Setup:** The system should be set up to run autonomously, with minimal human intervention. This includes ensuring the system starts and stops based on pre-programmed schedules or environmental conditions.
- **Remote Monitoring (if applicable):** For larger installations, remote monitoring can be incorporated. This would involve setting up sensors or IoT technology to monitor the system's performance and detect any issues such as a malfunctioning pump or motor. Alerts can be sent to maintenance teams to ensure prompt action.

5.4.7 Maintenance and Troubleshooting

Routine maintenance is necessary to ensure the system continues to function optimally over time. Tasks involved include:

- **Regular Cleaning of Components:** The wiper blade and water pump must be checked and cleaned regularly to prevent clogging or wear. The wiper blade may need to be replaced periodically, depending on usage and environmental conditions.

- **Checking for System Faults:** The Arduino, motor, and pump should be inspected periodically to identify any faults or malfunctions. This includes checking for power issues, wear on the motor gears, or damage to electrical wiring.
- **Software Updates:** If any issues are identified during operation, the Arduino code can be modified or updated to improve functionality or add new features.

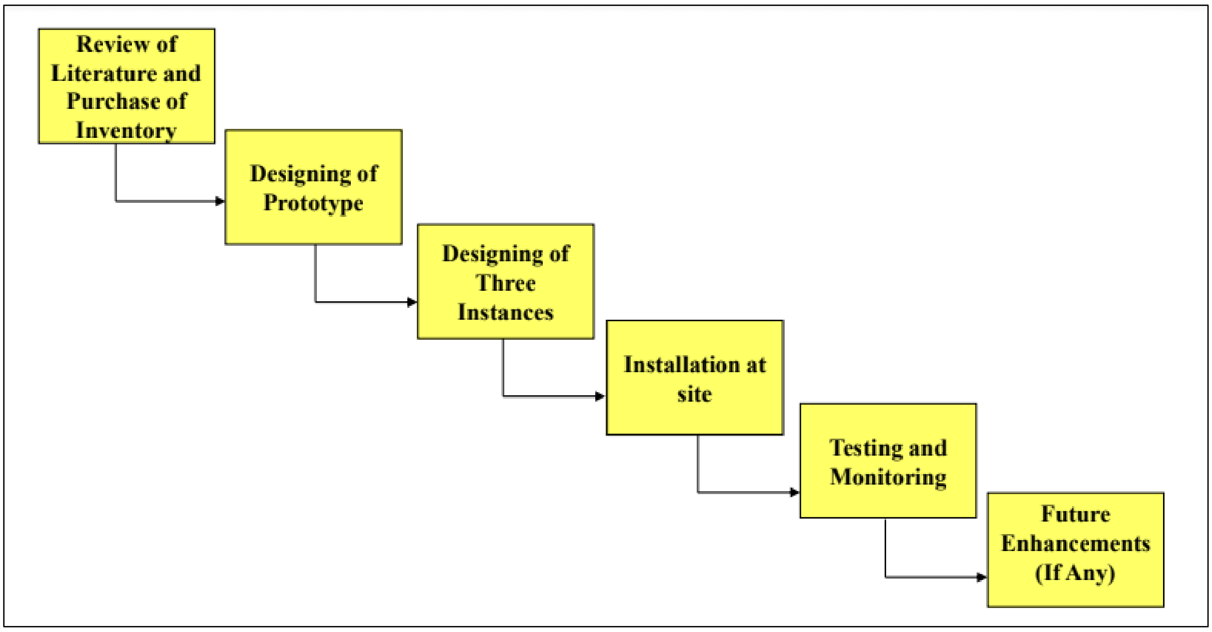

Figure 5.4.7 : Major Tasks involved in Proposed Project

6 PERFORMANCE ANALYSIS

6.1 System Testing

The framework going for delicate products is the looking at achieved on an outright, included machine to assess the machine's congruity with its exact necessities. gadget testing would also fall inside the range of the dark compartment looking at, and in this way, it must need no data around the interior structuring of the presence of mind or the code. It's miles a totally comparable deliberate check case lettering. inside the check case lettering we ought to be equipped for compose the check case circumstances and moreover the utilization cases.

6.2 Black Box Testing

The Black-box looking at is an approach to "test programming that uncovers out the ability and running of a product without the peering into the inward structures or into the operations, explicit data of the products inside shape, code and programming understanding is commonly not required". Furthermore, the analyser is enjoyably careful about unequivocally what our item is thought to do anyway it isn't responsive of ways it would do it. as a case, our analyser is responsive that one careful enter may restore a definite, never-ending yield yet it isn't sure generally how the item would convey the yield inside the essential spot.

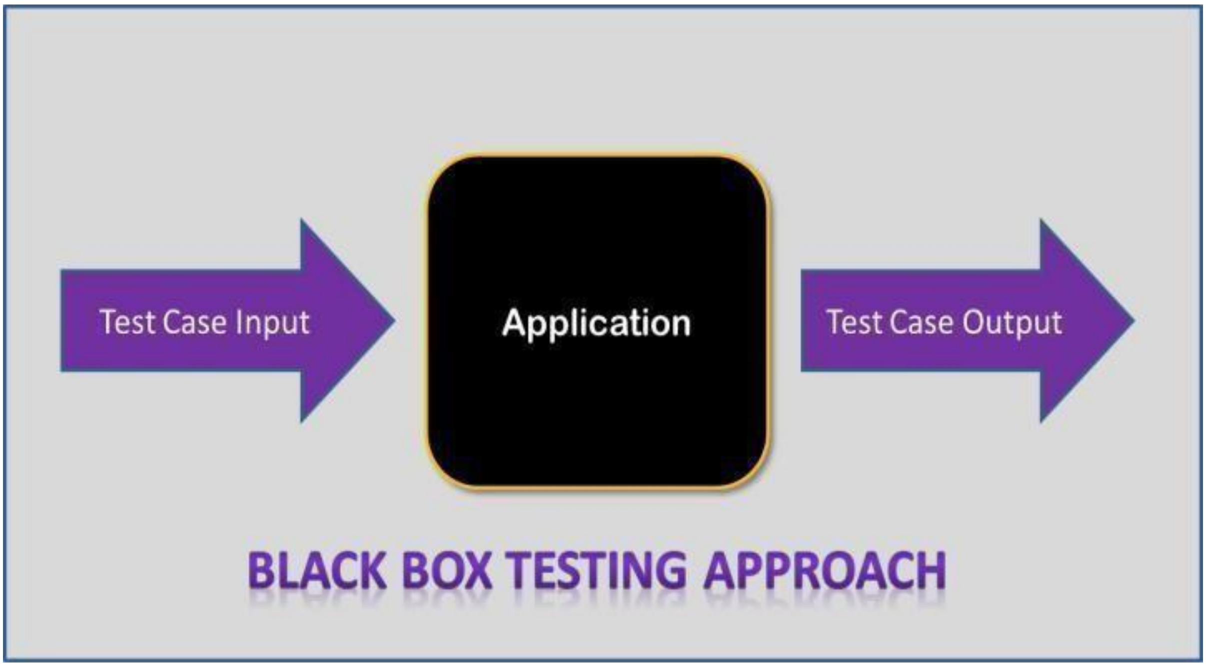

Figure 6.2 : Black Box Testing

6.3 Unit Testing

Throughout pc programming and coding, we have this unit testing assisting which of the product tests approaches with the methods for which specific units of the supply code, or a fixed of 1 and now and then additional PC programming component together with related control records, managing procedures, and working methodologies, are experienced, and analysed to see whether they are strong for use. Instinctively, we likewise can locate a unit to be the littlest checkable component of an apparatuses. For this situation of the procedural programming, our unit could have been a whole module, but it's miles more usually a man or woman manner or characteristic.

The objective of unit checking out is in order to separate every detail of this system and to illustrate that the person factors are accurate.

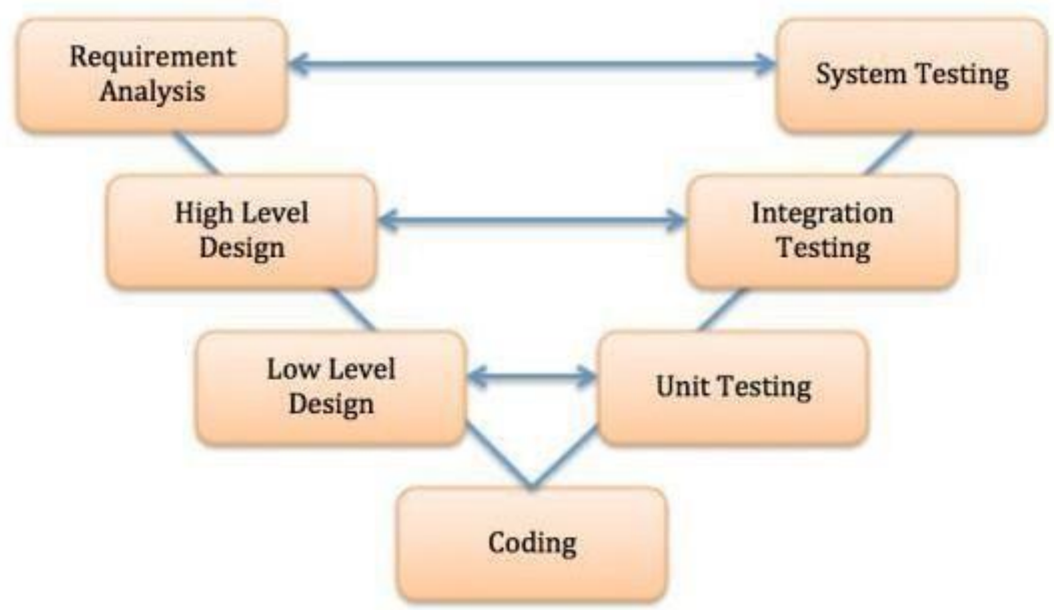

Figure 6.3: Unit Testing

7 CONCLUSION AND FUTURE RECOMMENDATIONS

7.1 Conclusion

The conclusion of the development of an Semi-Automatic solar panel cleaning system is a significant step forward in maintaining the efficiency and longevity of solar panels, especially in areas with high dust or pollution levels. By integrating components such as a wiper mechanism, water pump, and Arduino microcontroller, the system can perform regular, automated cleaning cycles that reduce the need for manual maintenance. This design not only ensures that solar panels operate at their highest efficiency by preventing dirt accumulation, but it also reduces operational costs associated with regular cleaning, ultimately contributing to greater energy production and sustainability.

The prototype demonstrates the potential of using simple yet effective components to create a reliable and autonomous system. The addition of a voltage regulator, stable power supply setup, and controlled water distribution system further enhances the system's durability and effectiveness. The adaptability of the Arduino microcontroller allows for future scalability, such as adding sensors to detect dust levels and adjusting the cleaning frequency dynamically.

Overall, this project provides a practical, low-cost solution to a common challenge faced by solar energy installations. With continued optimization and potential for integration into larger solar farms, this Semi-Automatic cleaning system offers a way to maximize the environmental and economic benefits of solar energy, making it an attractive addition to solar panel maintenance strategies. The project serves as a foundation for future advancements in automated solar maintenance, supporting the growth of renewable energy infrastructure worldwide.

7.2 Future Recommendations

7.2.1 Incorporation of Dust and Dirt Sensors:

Adding sensors to detect dirt or dust levels on the surface of the panels could enable the system to operate more dynamically. Instead of running on a fixed schedule, the system could initiate cleaning cycles based on the actual condition of the panels, optimizing water and energy use by cleaning only when necessary. This upgrade would make the system more adaptable to varying environmental conditions and help conserve resources.

7.2.2 Weather-Based Scheduling with IoT Integration:

Integrating the system with IoT technology would allow it to track weather patterns and adjust its operation accordingly. For example, the system could avoid cleaning during or right before rain, saving water and energy. Remote monitoring and control through IoT would also enable operators to monitor the system's status, receive alerts for maintenance, and adjust settings remotely, improving system accessibility and maintenance efficiency.

7.2.3 Enhanced Water Efficiency Techniques:

As water conservation is crucial in many regions, future designs could incorporate water-saving technologies like atomizers or mist nozzles, which use minimal water to achieve effective cleaning. Additionally, the system could recycle water through a filtration unit, which would allow for sustainable water use, especially in large-scale solar installations.

7.2.4 Solar-Powered and Energy-Optimized Components:

To further enhance the system's independence, using solar-powered components, such as solar-powered pumps or motors with low power consumption, would ensure that the cleaning system operates solely on renewable energy. Exploring energy-efficient motors and alternative voltage regulators would also reduce overall power consumption, making the system suitable for off-grid solar arrays and minimizing its energy footprint.

7.2.5 Improved Wiper Blade Materials and Design:

Research into more durable and flexible wiper blade materials, resistant to wear and capable of effective cleaning without scratching the panel surface, could significantly extend maintenance intervals. Additionally, designs that prevent debris buildup on the wiper itself would allow the system to maintain its cleaning efficacy over longer periods without requiring manual intervention.

7.2.6 Automated Maintenance Alerts and Diagnostics:

Integrating self-diagnostics to monitor system health, such as motor torque or water pump performance, could improve maintenance by Semi-Automatically alerting operators to any issues or necessary repairs. This proactive maintenance approach would reduce downtime, prevent sudden system failures, and increase the system’s longevity.

7.2.7 Adaptability to Various Panel Configurations and Sizes:

Future designs could be modular or adjustable to fit different solar panel sizes and configurations, such as angled or vertically mounted panels. This flexibility would make the cleaning system applicable across diverse solar installations, increasing its usability in different regions and conditions.

7.2.8 Development of Autonomous or AI-Based Cleaning Algorithms:

Using machine learning or AI-based algorithms, the system could optimize its cleaning schedules based on historical data, environmental factors, and panel performance trends. This intelligent approach would allow the system to learn and adapt over time, maximizing cleaning efficiency while minimizing energy and water use.

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