A

Project Work-II Report

on

Automatic Solar Panel Cleaning Robot

Submitted in Partial Fulfilment of the Academic Requirements of Degree

Bachelor of Engineering

in

ELECTRONICS AND COMMUNICATION ENGINEERING

by

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We declare that this project report titled **Automatic Solar Panel Cleaning Robot** submitted in partial fulfillment of the degree of Bachelor of Engineering in Electronics and Communication Engineering is a record of original work carried out by us under the supervision of **Dr. B. Sarala**, and has not formed the basis for the award of any other degree or diploma, in this or any other Institution or University. In keeping with the ethical practice in reporting scientific information, due acknowledgements have been made wherever the findings of others have been cited.

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ABSTRACT

This report presents the design and development of a fully autonomous solar panel cleaning robot aimed at enhancing the efficiency and longevity of solar energy systems. With the accumulation of dust and debris significantly reducing power output—by as much as 50% if left uncleaned for extended periods—this project addresses the critical need for a reliable maintenance solution in solar farms. The proposed robot employs advanced sensing technology and a water-assisted cleaning mechanism to operate independently, ensuring optimal performance of solar panels.

The solar panel cleaning robot is built around an Arduino microcontroller, which integrates multiple components such as infrared (IR) sensors for edge detection, a rain detection module for safety, and a cleaning mechanism featuring rotating brushes and a water pump. The robot is programmed to follow a boustrophedon cleaning path to ensure comprehensive coverage of the solar panel surface while avoiding potential hazards. Testing results demonstrated over 90% cleaning efficiency and reliable autonomous operation under various environmental conditions.

Implementation of the system involved the careful selection and integration of hardware and software tools. The Arduino platform facilitated seamless communication between sensors and motor drivers, allowing for real-time adjustments during operation. The use of cost-effective components ensured the project's accessibility for medium to large-scale solar installations. Additionally, the potential applications of this robotic solution extends beyond just cleaning; it lays the groundwork for future integration with IoT technologies for remote monitoring and scheduling, further streamlining solar panel maintenance processes.

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CHAPTER I

INTRODUCTION OF SOLAR PANEL CLEANING ROBOT

1.1. Introduction

The introduction traces humanity's increasing need for and utilization of energy throughout history. Initially, primitive man's energy requirements were met primarily through food obtained by hunting. The discovery of fire led to an increase in energy use for cooking and agriculture, utilizing wood and biomass. Domestication of animals further expanded energy use for labour. Historically, before the industrial revolution, energy sources were predominantly renewable, with the sun being the ultimate origin, directly or indirectly, powering activities like sailing and water wheels. The industrial revolution, marked by the invention of the steam engine around 1700 AD, introduced a significant shift with the large-scale adoption of coal as a new energy source. The text then transitions to modern times, highlighting the use of solar energy through solar panels for electricity generation, its widespread application in industries (often in large arrays), and its growing role in household energy needs.

1.2. Problem Statement

The core problem identified is the decrease in efficiency of photovoltaic (PV) modules due to the accumulation of dust on their surface. This dust layer reduces the amount of solar radiation reaching the solar cells, leading to a loss in generated voltage and power. The problem is exacerbated during long periods without rain, where daily energy loss can exceed 20%. The text also notes that the irradiance loss is not constant throughout the day and is influenced by the sunlight incident angle.

Different types of pollutants (red soil, ash, sand, calcium carbonate, and silica) have been shown to cause a drop in PV module voltage and output power depending on the accumulated mass and pollutant type. Increased module temperature further contributes to a larger reduction in efficiency when dust is present. Maintaining clean and cool PV modules is crucial for efficient system performance. The current human-based cleaning methods are highlighted as time-consuming and requiring significant manpower and money, especially for large solar panel arrays. The problem is particularly significant for large ground-based solar parks with vast numbers of panels.

1.3. Objectives of the Project

The main objectives of this project are:

- Address the decrease in solar panel efficiency caused by dust accumulation.

- Maintain and improve the energy generation efficiency of photovoltaic modules.
- Keep the surface of solar panels as clean as possible to maximize energy capture.
- Develop an automated cleaning machine/system for solar panels.
- Create a system that can clean and move easily on the glass surface of solar panels.
- Remove accumulated dust on the surface of solar panels on a regular basis.
- Maintain the intended output of solar power plants.
- Boost the efficiency of solar panels by increasing their energy output.
- Provide a quick and cost-effective cleaning solution.
- Develop a bot capable of cleaning multiple solar panels in an array.
- Increase solar panel efficiency by at least the same amount that rainfall can.

1.4. Scope and Limitations

1.4.1. Scope:

- The project focuses on developing an automated cleaning solution specifically designed for solar panels, particularly targeting large ground-based solar arrays. The system aims to address the issue of dust accumulation, which is identified as a major factor reducing solar panel efficiency.
- The proposed solution involves the use of robotics to perform the cleaning task autonomously, thereby eliminating the need for human labor in the cleaning process. The scale mentioned in the problem statement, up to an operating park of 22,000 panels (20,000 square meters), suggests the scope includes developing a system capable of operating within such large-scale installations.
- The cleaning mechanism itself is implied to be designed for removing dust particles from the glass surface of the panels to restore efficiency.

1.4.2. Limitations:

- Dependence on proper circuitry and sensors which can sometimes fail or give inaccurate detection of dust or dirt.
- The robot's cleaning efficiency could be affected by environmental factors like heavy dust accumulation, extreme weather, or panel slope.
- Initial setup and maintenance costs, though automation reduces operational risk and manual labour.
- The system might need remote operation capability and wireless monitoring, which could face issues related to connectivity or system reliability.
- Limited to cleaning flat solar panels and may not work efficiently on all panel types or installations.

1.5. Organization of the Report

This report is organized as follows:

Chapter 1: Introduction

This project develops a fully autonomous solar panel cleaning robot using an Arduino-based control system integrated with IR sensors, a rain detection module, and a water-assisted cleaning mechanism. The robot was designed to follow a boustrophedon (zigzag) cleaning path to ensure full panel coverage while avoiding edges using IR-based detection.

Chapter 2: Literature Survey

This chapter reviews technologies related to solar panel cleaning systems and their efficiency. It discusses various cleaning methods, including manual and mechanical options, while addressing the challenges posed by dust accumulation, which can reduce energy output by 10% to 50%. The chapter highlights advancements in robotic cleaning technologies that use sensors for autonomous operation, offering improved effectiveness and reduced labor costs. Despite higher initial costs, these systems can enhance energy output and sustainability, with future research focusing on sensor technology and IoT integration for better monitoring.

Chapter 3: System Design

This chapter provides a detailed description of the system design, including the motorized structure, sensor integration, and the cleaning mechanism. It discusses the selection of components, system architecture, and design considerations aimed at developing a robust and efficient cleaning robot.

Chapter 4: Implementation

This chapter outlines the implementation process, focusing on the integration of hardware and firmware to achieve autonomous operation. It details the calibration of sensors, motor driver testing, and the synchronization of sensor data with motor control for efficient movement.

Chapter 5: Results and Discussion

This chapter presents the results of the robot's performance during testing. It evaluates cleaning efficiency, edge detection reliability, and the effectiveness of the rain detection mechanism. The analysis is performed in the context of the project's objectives and key findings.

Chapter 6: Conclusion & Future Work

The final chapter summarizes the project’s key findings, discusses implications, and offers recommendations for future improvements. It emphasizes the potential for scalability and the integration of advanced features for broader applications in solar energy installations.

CHAPTER II

LITERATURE REVIEW

This chapter analyses previous research, identifies key advancements, and evaluates the merits and demerits of existing solutions.

2.1 Literature Review

The literature review for automatic Solar Panel Cleaning Robot critically analyzes existing research and automation, providing insights into advancements, limitations and emerging trends in the field.

2.1.1 Existing Methods

- **V. Bhuvaneswari et al. (2014)** described The Internet of Things (IoT) is the most promising area which penetrates the advantages of Wireless Sensor and Actuator Networks (WSAN) and Pervasive Computing domains. Different applications of IoT have been developed and researchers of IoT well identified the opportunities, problems, challenges, and the technology standards used in IoT such as Radiofrequency Identification (RFID) tags, sensors, actuators, mobile phones, etc. This paper is of two-fold; the first fold covers the different applications that adopted smart technologies so far. The second fold of this paper presents the overview of the sensors and its standards.

- **Swanand S. Wable et al. (2017)** proposed the Solar Panels Farms are situated in dirt and dust areas which are mostly in case of tropical countries. The performance of solar panels depends on various factors, the power generated by farm can decreased if there is dust and dirt on panels and this is the main factor for reduction. One can assume a reduction of about 40% - 50%, if the panels are not clean properly for 1-2 months. So, to overcome this problem and to increase the efficiency of power production cleaning of module on regular basis is necessary. To clean the dust, an automatic cleaning robot is developed, which will clean the panels on regular interval of time. The mechanism is based on control circuit, DC motor; microfiber (bristles) to clean the panels. The paper provides you with the idea how the robot will work and its effect on the energy production by solar farms. It will also help to understand the problem arise due to not cleaning of solar cells.

- **Subhasri.G et al. (2018)** presented a sunlight-based framework is the device for orienting solar photovoltaic modules and solar thermal collectors toward the sun Thinking about the state of the art of the innovation, successful strategy, robust control philosophy and the potential added benefit of different research work which can be employed on an extensive scale in maintainable manner. Presently we are entering in a new period of processing innovation i.e., Internet of things (IoT). IoT is a sort of “universal global neural network” in the cloud which associates various things. The IoT is an intelligently connected devices and framework contain brilliant machine connecting and communicate with different machines, environments, objects and infrastructures and the radio frequency identification (RFID) and sensor network technologies will rise to meet this new challenge. Furthermore, the investigation gives the different related works on iot empowered solar panel monitoring modules for the proficient way of gain power from the solar radiation

- **Tushar Pokharkar et al. (2018)** presented the solar PV modules are employed in tropical countries like India. Dust and dirt particles accumulating on PV panels decreases the solar energy reaching the cells, thereby reducing their overall power output. The power output reduces as much as by 50% if the module is not cleaned for a month. Hence, cleaning the PV panels is a problem of great practical engineering interest in solar PV power generation. In this paper, the problem is reviewed and methods for dust removal are discussed. To regularly clean the dust, an automatic cleaning system has been designed, which senses the dust on the solar panel and cleans the module automatically. This automatic system helps in maintaining the overall output of the solar firm. For cleaning the PV modules, a mechanism consists of a sliding brush has been developed. In terms of daily energy generation, the presented automatic-cleaning scheme provides about 30% more energy output when compared to the dust accumulated PV module.

- **Abhishek Naik et al. (2019)** proposed the solar PV modules are employed in dusty environments which is the case in tropical countries like India. The dust gets accumulated on the front surface of the module and blocks the incident light from the sun. It reduces the power generation capacity of the module. The power output reduces as much as by 50% if the module is not cleaned for a month. In order to regularly clean the dust, an automatic cleaning system has been designed, which senses the dust on the solar panel and also cleans the module automatically. In terms of daily energy generation, the presented automatic cleaning scheme provides about 30% more energy output when compared to the dust accumulated PV module.

- **Gargi Ashtaputre et al. (2019)** proposed the efficiency of Solar PV panel is greatly affected due to the accumulation of dust, dirt, and sea salt on panel. This paper aims at developing a low-cost automatic robot which will smartly clean the panel. The project is divided into two parts: Cleaning System and Monitoring System. Cleaning task is completed according to the data received from monitoring system. Wireless technology has been implemented in order to collect all the data from individual panel. The power output of each panel is monitored thoroughly and depending on the information collected at each node, the cleaning action is triggered. This system is also able to detect breakage of panel. The system can be operated remotely, and user can access all the information on field from any part of the world.

- **Milan Vaghani et al. (2019)** presented transparency in cleaning system by using the most newly invented technology, which provide a better performance, integrity, consistency, cost-effective and scalable solution for the removal of dust and speck. The presented cleaning system provides about 32% more energy output compared to the dust accumulated solar panel. This system is control by application from whole world. Also, this system reduces workforce for cleaning of solar panel. This is automatic solar panel cleaning system.

2.1.2. Proposed Method

The proposed method for the automatic solar panel cleaning robot involves a sequence of actions executed by a carrier robot and the cleaning robot it transports. The process begins with the carrier robot, carrying the cleaning robot, moving towards the solar panel requiring cleaning. Upon reaching the panel, the carrier robot utilizes its sensing capabilities to detect the presence of the solar panel and consequently stops its movement. Following this, the carrier robot transmits a signal to the cleaning robot, effectively instructing it to commence the cleaning operation. Upon receiving this signal, the cleaning robot activates and proceeds to traverse the entire length of the solar panel. To ensure comprehensive coverage of the panel's surface, the cleaning robot moves in both forward and lateral (left and right) directions. This cleaning activity is performed for a specified duration, after which the process for that panel is presumably complete. The provided text focuses on this sequence of transport, signalling, and movement patterns for cleaning, but does not elaborate on the specific mechanisms for sensing, signalling, or the physical cleaning action itself.

2.2. Comparison of Various Methods for Solar Panel Cleaning

In the quest for effective maintenance of solar panels, numerous cleaning methods have been developed, each with its unique advantages and disadvantages. This section provides a detailed comparative analysis of the existing methods, focusing on automation, cost, efficiency, environmental impact, and operational complexity.

1. Manual Cleaning

Overview: Manual cleaning remains a common method, especially for smaller solar installations. This involves human operators manually washing the panels, often utilizing water and cleaning agents.

Advantages:

- Low capital equipment cost.
- Flexibility in addressing specific panel conditions or dirt types.
- Immediate feedback on cleaning efficiency can be visually assessed.

Disadvantages:

- Labor-intensive and time-consuming, making it impractical for large installations.
- High recurring costs due to labor and potential service disruptions.
- Human error can lead to inconsistent cleaning results.
- Risk of potential physical damage to panels during cleaning.

2. Automated Robotic Cleaners

Overview: Automated robotic cleaners are increasingly being adopted due to their effectiveness and efficiency in maintaining solar panel cleanliness without human intervention.

Subtypes:

- **Tracked Robots:** Designed for rugged terrain and uneven surfaces, these robots move using tracks and are better suited for installations with varying gradients.
- **Wheeled Robots:** Lighter and easier to maneuver on flat surfaces, these robots generally use wheels for movement.

Advantages:

- Reduces labor costs and safety risks associated with manual cleaning.
- Capable of operating in adverse weather conditions without human supervision.
- Improved cleaning efficiency, often exceeding 90% dust removal.
- Systematic cleaning patterns ensure comprehensive coverage (e.g., bustrophedon path).

Disadvantages:

- Higher initial capital investment for acquisition and installation.
- Dependence on battery life can limit operational time unless connected to a reliable power source.
- Limited capability in detecting uniquely shaped or inclined solar panels.
- Varying performance based on terrain and environmental conditions (e.g., high winds can affect operation).

3. Waterless Cleaning Systems

Overview: These systems utilize brushes and squeegees without the need for water, relying on mechanical methods to dislodge and remove dirt.

Advantages:

- No water usage makes them environmentally friendly, conserving valuable resources.
- Reduced cleaning times as systems can operate faster without setup for water application.
- Lower risk of water-related panel damage due to reduced moisture exposure.

Disadvantages:

- May require more frequent cleaning cycles to achieve equivalent results compared to water-assisted systems.
- Difficult to remove stubborn dirt or contaminants, such as bird droppings or heavy dust accumulation, without water.
- Higher wear on brushes may lead to increased maintenance costs over time.

4. Hybrid Cleaning Systems

Overview: Hybrid systems combine the strengths of both water-assisted and waterless technologies, utilizing sensors and control systems to determine the most effective cleaning approach based on surface conditions.

Advantages:

- Optimize water use while maintaining effective cleaning performance.
- Can be programmed to adapt cleaning methods based on environmental and dirt conditions.
- Versatile application allows for various types of solar panel installations.

Disadvantages:

- Increased complexity in system design and programming, requiring advanced control algorithms and higher development costs.
- Potential for mechanical failure at points of integration between water and dry cleaning mechanisms.

5. IoT-Enabled Smart Cleaning Solutions

Overview: Integrating Internet of Things (IoT) technology, these solutions allow for data collection and remote monitoring of cleaning processes. Systems can be programmed for periodic cleaning based on weather forecasts or pollution levels.

Advantages:

- Enables proactive maintenance, reducing downtime and ensuring optimal solar panel efficiency.
- Remote monitoring allows for immediate response to issues and reduces on-site visits.
- Data-driven insights can optimize cleaning schedules and routine maintenance, enhancing overall system management.

Disadvantages:

- High initial costs for installation and setup of IoT infrastructure.
- Reliance on internet connectivity and potential technical issues with system integration.
- Data privacy concerns if not properly managed and secured.

Conclusion

In summary, selecting the appropriate solar panel cleaning method involves weighing the benefits against the limitations of each approach. Manual cleaning is the most cost-effective but lacks efficiency for larger installations. Automated robots offer a solution that enhances efficiency and minimizes labour costs, although they require a more substantial initial investment. Waterless and hybrid systems address environmental concerns while maintaining cleanliness, but may not perform as well under certain conditions. Finally, IoT-enabled solutions represent the future of solar panel maintenance, leveraging data-driven insights for optimal operational efficiency. Ultimately, the choice of method will depend on specific installation contexts, budget constraints, and maintenance goals.

2.3. Summary of the Analysis

The reviewed literature highlights significant challenges and advancements in maintaining the efficiency of solar photovoltaic (PV) panels, particularly in dusty and harsh environmental conditions common to tropical regions. Dust and other pollutants such as dirt, pollen, sea salt, and bird droppings drastically reduce solar panel efficiency—by as much as 10% to 50% depending on accumulation and cleaning frequency. Manual cleaning methods, while effective, are labour-intensive, costly, and impractical for large installations.

Many existing cleaning solutions incorporate advanced automation technologies including microcontroller-based systems, wireless monitoring, IoT integration, and robotic cleaning arms with multiple degrees of freedom. These systems deliver high cleaning efficiency and energy gains of about 30% compared to dirty panels. However, they often require complex hardware, advanced control algorithms, and significant computational resources, which may increase system cost and reduce accessibility.

In contrast, the proposed solar panel cleaning robot in this project adopts a cost-effective and straightforward design. It uses an Arduino microcontroller to control a lightweight robot equipped with cleaning mechanisms such as brushes and motors. The robot autonomously travels across panels, cleaning dust and debris to maintain maximum solar transmittance. Its aluminium construction ensures low weight and easy manoeuvrability. This approach reduces operational power consumption, improves maintenance, and lowers recurring costs, making it practical for medium to large solar farms.

The system does not rely on heavy computational vision algorithms or complex navigation but demonstrates effective cleaning performance, leading to increased energy output and reliable solar panel operation. Periodic and frequent cleaning cycles are integral to maintaining system efficiency, reducing power generation losses up to 30% caused by dust accumulation.

Advantages of the Proposed Cleaning Robot System:

- Low cost and simple control architecture based on Arduino microcontroller.
- Lightweight and easy to maintain mechanical design.
- Economically favourable compared to manual cleaning, especially for large solar panel arrays.
- Improves power output and operational lifetime of solar panels.
- Potential integration with IoT features for remote monitoring and cleaning scheduling.

Limitations and Considerations:

- Limited intelligent navigation or environmental sensing capabilities.
- May require manual setup or environmental adjustment to optimize cleaning performance.
- Not optimized for highly inclined or irregular panel arrays.
- Cleaning efficiency dependent on robot path planning and environmental factors like heavy dust or weather conditions.

Recommendations for Implementation:

1. Utilize microcontroller-based automation (Arduino) for simple and reliable control of cleaning mechanisms.
2. Design lightweight robot frame using aluminium and low-power motors for efficient cleaning operation.

3. Implement periodic cleaning cycles based on time or dust accumulation sensors to maintain panel transmittance.
4. Consider modular machine architecture to enable scalability and adaptability to various solar farm sizes.
5. Integrate basic sensors (e.g., ultrasonic) for obstacle detection to prevent mechanical damage.
6. Explore wireless communication for remote monitoring and status reporting.
7. Conduct performance testing under realistic environmental conditions to optimize cleaning parameters.

In summary, this project offers a practical and low-cost robotic cleaning solution to combat the significant energy losses in PV systems caused by dust accumulation. By combining straightforward hardware and control logic, the cleaning robot helps sustain solar panel efficiency, reduce maintenance costs, and improve power output — making it suitable for widespread adoption in solar energy installations ranging from small farms to large solar parks. While it may not match the sophistication of high-end industrial systems, it balances affordability, simplicity, and functional performance effectively.

CHAPTER III

SOLAR PANEL CLEANING ROBOT

3.1. Overview of the System

The automatic solar panel cleaning robot is designed to clean dust and debris from solar panels autonomously, thereby maintaining and improving their efficiency. The robot uses sensors to detect the position and surface of the panels and operates without human intervention through embedded control algorithms implemented on an Arduino microcontroller.

The system consists of:

- A motorized structure designed to move across the surface of solar panels.
- Enables the robot to traverse from one end of the panel to the other, allowing full coverage.
- Typically includes DC gear motors for mobility and gripping wheels or rails to maintain stability on inclined surfaces.
- Powered by DC motors controlled through motor drivers.
- Mechanically synchronized with the robot's movement to clean as it moves.
- IR (Infrared) Sensors: Detect panel edges and prevent the robot from falling off.

  Help with obstacle avoidance and directional control.
- Rain Sensor: Detects rainfall or high moisture. Automatically halts cleaning operations to prevent short circuits or unnecessary cleaning.
- LED Indicators: Provide visual feedback for system status (e.g., ON/OFF, cleaning, rain detected).
- Control System: Serves as the central controller for all sensors, motors, and logic operations. Runs firmware written in Embedded C, developed using the Arduino IDE
- L293D Motor Driver IC: Drives DC motors and water pumps by supplying bidirectional current.
- Enables control of motor speed and direction via Arduino digital outputs (PWM and logic levels).

3.2. Block Diagram

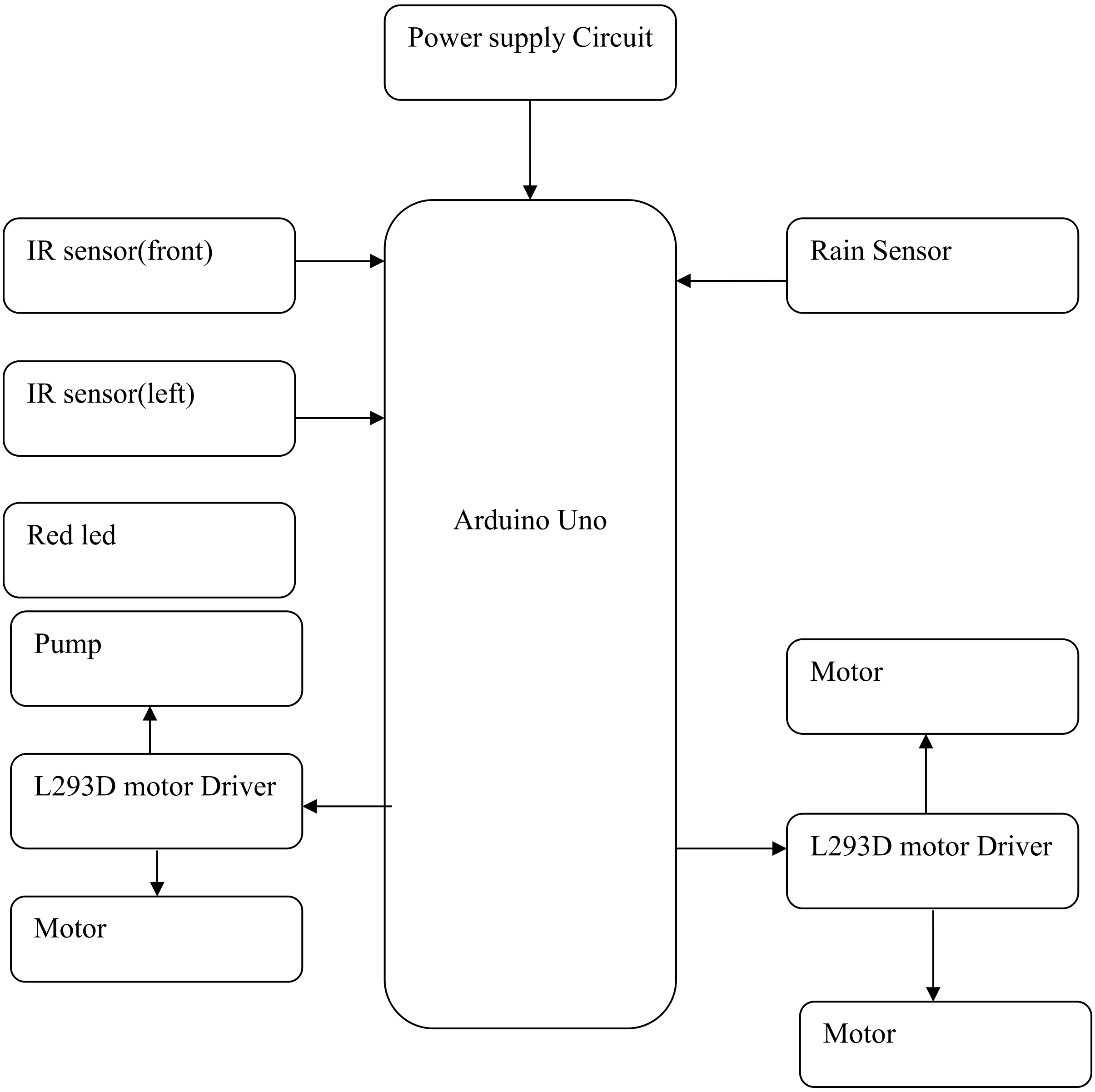


Fig 3.1. Block diagram

The block diagram of the Automatic Solar Panel Cleaning Robot represents the overall architecture of the system, outlining the main hardware components and their interconnections. Here is a detailed textual explanation of the block diagram:

Power Supply Circuit:

- Provides electrical power to all the components of the robot, including the microcontroller, sensors, motors, and pumps.

- Ensures stable voltage and current necessary for reliable operation.

Arduino Uno (Control System):

- Serves as the central controller of the robot.
- It receives inputs from various sensors and processes them to control actuators such as motors and pumps.
- Runs embedded control algorithms written in Embedded C using the Arduino IDE.
- Handles the logic for autonomous cleaning, edge detection, rain detection, and path navigation.

IR Sensors:

- Positioned at the front and left of the robot.
- These sensors emit infrared light and detect the reflected signal to sense the edges of solar panels.
- Their primary role is to prevent the robot from moving off the panel surface by accurately detecting boundaries.
- Also assist in obstacle avoidance and maintaining proper directional control during cleaning.

Rain Sensor:

- Detects the presence of rainfall or high moisture levels.
- When rain is detected, it sends a signal to the Arduino to halt all cleaning activities immediately.
- Helps in protecting electrical components from water damage and conserves water by stopping unnecessary cleaning during rains.

Motors (Driven by L293D Motor Driver):

- DC motors are used to move the robot across the surface of the solar panel.
- Two separate motors are controlled via L293D motor driver ICs which supply bidirectional current, enabling forward and backward motion.
- The motor driver IC interprets control signals from the Arduino to vary motor speed and direction using PWM and logic levels.

Water Pump (Also Controlled via L293D Motor Driver):

- Activated as part of the cleaning mechanism to assist in dust removal.
- Receives control signals from the Arduino to operate only when required, optimizing water usage.

Rotating Brushes (Motors):

- Attached to the cleaning mechanism.
- Rotate to brush off dust and debris from the solar panel surface.
- Operate synchronously with robot movement for effective cleaning.

LED Indicators:

- Provide visual feedback about the system status, such as power on/off, cleaning in progress, or rain detection.
- Help in easy troubleshooting and monitoring during operation.

How It Works as a System:

- The power supply energizes the entire system.
- The Arduino receives environmental data from the IR sensors and rain sensor.
- Based on sensor data, the Arduino decides the robot's movement and cleaning operations.
- If the IR sensors detect the panel edge, the Arduino stops or changes movement angle to prevent falling.
- If rain is detected, cleaning stops immediately.
- During operation, the Arduino controls motors for navigation and brushes and pump for cleaning.
- LED indicators update the status to users.

This block diagram integration ensures the robot achieves autonomous navigation, efficient cleaning, edge protection, and safety via rain detection in a low-cost, reliable design,,.

3.3. Hardware Components and Specifications

This section describes the hardware components used in the design and implementation of the automatic solar panel cleaning robot. Each component has been selected for specific roles in ensuring accurate detection, movement, control, and cleaning.

3.3.1 SOLAR PANEL

A solar panel is a device that collects and converts solar energy into electricity or heat. It known as Photovoltaic panels, used to generate electricity directly from sunlight Solar thermal energy collection systems, used to generate electricity through a system of mirrors and fluid-filled tubes solar thermal collector, used to generate heat solar hot water panel, used to heat water. It is energy portal. A solar power technology that uses solar cells or solar photovoltaic arrays to convert light from the sun directly into electricity. Photovoltaics is in which light is converted into electrical power. It is best known as a method for generating solar power by using solar cells packaged in photovoltaic modules, often electrically connected in multiples as solar photovoltaic arrays to convert energy from the sun into electricity. The photovoltaic solar panel is photons from sunlight knock electrons into a higher state of energy, creating electricity.

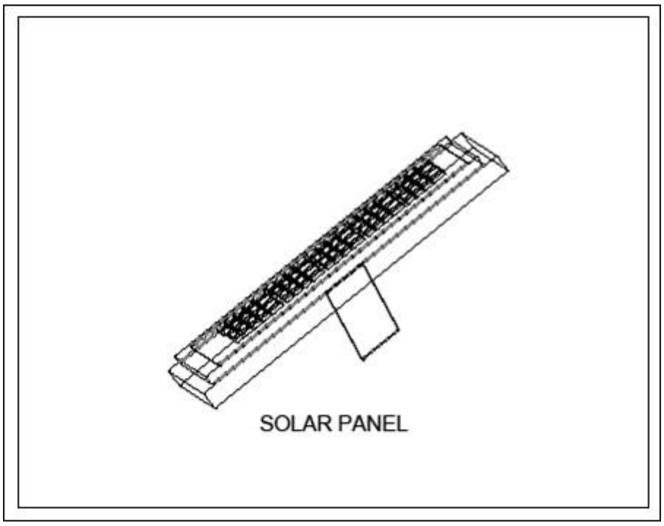


Fig 3.2.Solar Panel

Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a battery. A less common form of the technologies is thermophotovoltaics, in which the thermal radiation from some hot body other than the sun is utilized. Photovoltaic devices are also used to produce electricity in optical wireless power transmission.

3.3.2. BATTERY

In our project we are using secondary type battery. It is rechargeable type. A battery is one or more electrochemical cells, which store chemical energy and make it available as electric current. There are two types of batteries, primary (disposable) and secondary (rechargeable), both of which convert chemical energy to electrical energy. Primary batteries can only be used once because they use up their chemicals in an irreversible reaction. Secondary batteries can be recharged because the chemical reactions they use are reversible; they are recharged by running a charging current through the battery, but in the opposite direction of the discharge current. Secondary, also called rechargeable batteries can be charged and discharged many times before wearing out. After wearing out some batteries can be recycled. Batteries have gained popularity as they became portable and useful for many purposes. The use of batteries has created many environmental concerns, such as toxic metal pollution. A battery is a device that converts chemical energy directly to electrical energy it consists of one or more voltaic cells. Each voltaic cell consists of two half cells connected in series by a conductive electrolyte. One half-cell is the positive electrode, and the other is the negative electrode. The electrodes do not touch each other but are electrically connected by the electrolyte, which can be either solid or liquid. A battery can be simply modelled as a perfect voltage source which has its own resistance, the resulting voltage across the load depends on the ratio of the battery's internal resistance to the resistance of the load.

When the battery is fresh, its internal resistance is low, so the voltage across the load is almost equal to that of the battery's internal voltage source. As the battery runs down and its internal resistance increases, the voltage drop across its internal resistance increases, so the voltage at its terminals decreases, and the battery's ability to deliver power to the load decreases.

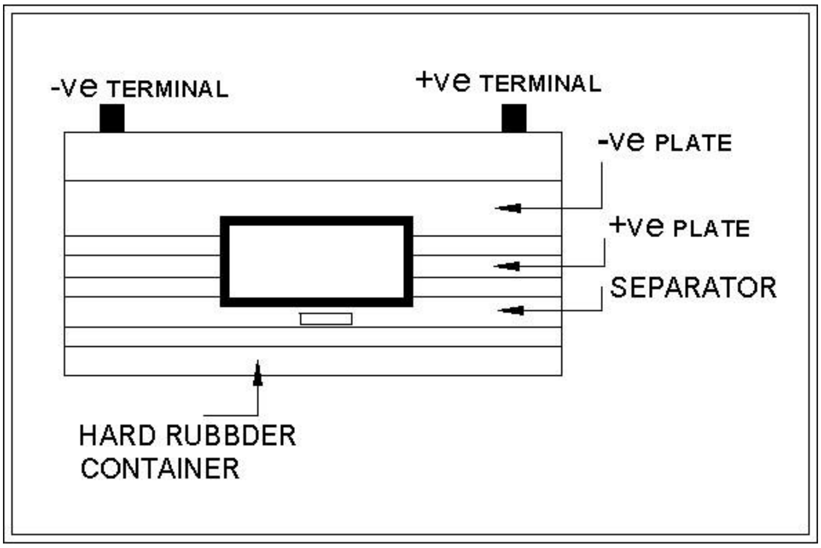


Fig 3.3. Battery

3.3.3. D.C MOTOR:

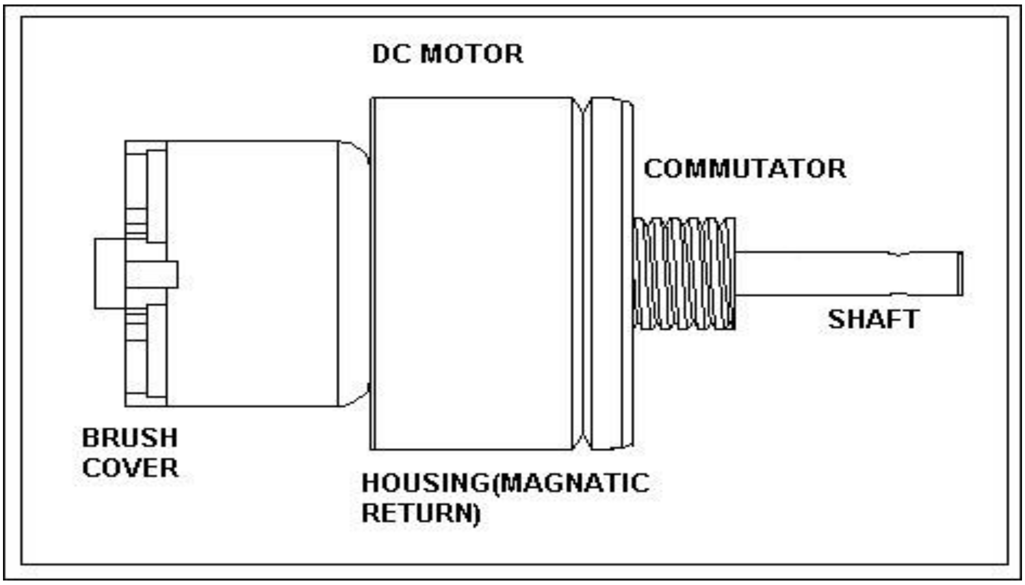


Fig 3.4. DC Motor

PRINCIPLES OF OPERATION

In any electric motor, operation is based on simple electromagnetism. A current-carrying conductor generates a magnetic field; when this is then placed in an external magnetic field, it will experience a force proportional to the current in the conductor, and to the strength of the external magnetic field. As you are aware of from playing with magnets as a kid, opposite (North and South) polarities attract, while like polarities (North and North, South and South) repel. The internal configuration of a DC motor is designed to harness the magnetic interaction between a current-carrying conductor and an external magnetic field to generate rotational motion.

Let's start by looking at a simple 2-pole DC electric motor (here red represents a magnet or winding with a "North" polarization, while green represents a magnet or winding with a "South" polarization).

Every DC motor has six basic parts -- axle, rotor (armature), stator, commutator, field magnet(s), and brushes. In most common DC motors, the external magnetic field is produced by high-strength permanent magnets. The stator is the stationary part of the motor -- this includes the motor casing, as well as two or more permanent magnet pole pieces. The rotor (together with the axle and attached commutator) rotate with respect to the stator. The rotor consists of windings (on a core), the windings being electrically connected to the commutator. The above diagram shows a common motor layout -- with the rotor inside the stator (field) magnets.

The geometry of the brushes, commutator contacts, and rotor windings are such that when power is applied, the polarities of the energized winding and the stator magnet(s) are misaligned, and the rotor will rotate until it is almost aligned with the stator's field magnets. As the rotor reaches alignment, the brushes move to the next commutator contacts, and energize the next winding. Given our example two-pole motor, the rotation reverses the direction of current through the rotor winding, leading to a "flip" of the rotor's magnetic field, driving it to continue rotating. In real life, though, DC motors will always have more than two poles (three is a very common number). This avoids "dead spots" in the commutator. You can imagine how with our example two-pole motor, if the rotor is exactly at the middle of its rotation (perfectly aligned with the field magnets), it will get "stuck" there. Meanwhile, with a two-pole motor, there is a moment where the commutator shorts out the power supply. This would be bad for the power supply, waste energy, and damage motor components as well. Yet another disadvantage of such a simple motor is that it would exhibit a high amount of torque "ripple" (the amount of torque it could produce is cyclic with the position of the rotor).

So, since most small DC motors are of a three-pole design, let us tinker with the workings of one via an interactive animation (JavaScript required):

DC MOTOR CALCULATION

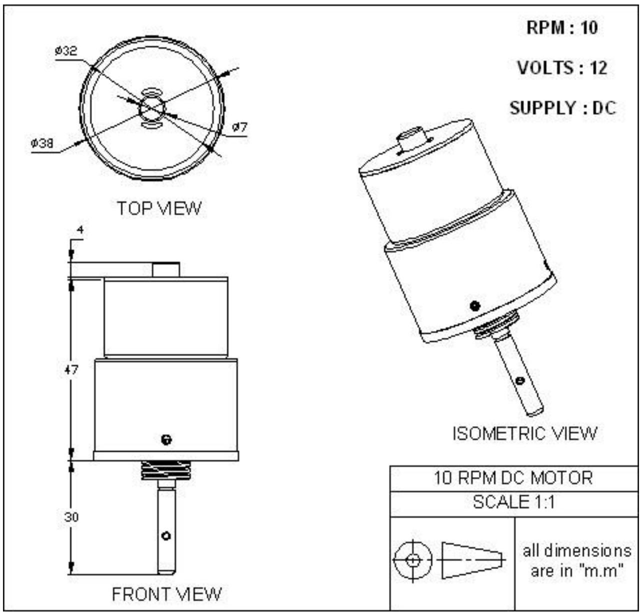


Fig3.5.Dimension of 100 RPM Motor

Motor specification:

Motor Type: DC Geared motor

Speed = 10

Volt = 12

Watt = 6

Motor calculation:

To find the rpm of the motor:

Rpm = 120 x Frequency / No. of Poles

Standard = 120

Frequency =1.125

No. of Poles = 3

There fore

Rpm = 120 x Frequency / No. of Poles

= 120x 1.125 /3

= 10 rpm

To find the torque of the motor P = 2x3.14x nm /60

T = P x 60/2 x 3.14 x nm

T =6 x 60/2 x 3.14 x 10

T= 1.27 N-m

3.3.4. WHEEL

Fig 3.6. Wheel

A wheel is a circular device that is capable of rotating on its axis, facilitating movement or transportation or performing labour in machines. A wheel together with an axle overcomes friction by facilitating motion by rolling. In order for wheels to rotate a moment needs to be applied to the wheel about its axis, either by way of gravity or by application of another external force. Common examples are found in transport applications. More generally the term is also used for other circular objects that rotate or turn, such as a Ship's wheel and flywheel. The wheel originated in ancient.

The wheel is a device that enables efficient movement of an object across a surface where there is a force pressing the object to the surface. Common examples are a cart drawn by a horse, and the rollers on an aircraft flap mechanism.

3.3.5. WATER PUMP

A pump is a device used to move gases, liquids, or slurries. A pump moves liquids or gases from lower pressure to higher pressure and overcomes this difference in pressure by adding energy to the system such as a water system. A gas pump is called a compressor, except in very low pressure-rise applications, such as in heating, ventilating, and air-conditioning, where the operative equipment consists of fans or blowers.

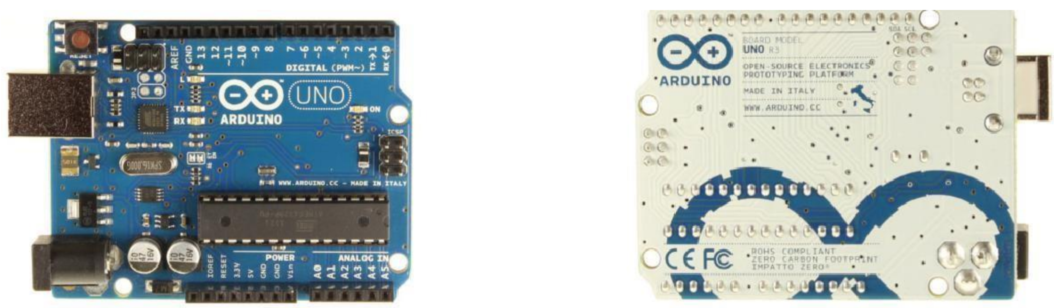
Pumps work by using mechanical forces to push the material, either by physically lifting, or by the force of compression. Hand-operated, reciprocating, positive displacement, water pump. A positive displacement pump causes a liquid or gas to move by trapping a fixed amount of fluid or gas and then forcing displacing that trapped volume into the discharge pipe. They are inexpensive and are used extensively for pumping water out of bunds or pumping low volumes of reactants out of storage drums. Conversion of added energy to increase in kinetic energy increase in velocity. Conversion of increased velocity to increase in pressure. Conversion of Kinetic head to Pressure Head.

Fig 3.7. DC Water Pump

3.3.6. ARDUINO

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. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started.

The Uno differs from all preceding boards in that it does not use the FTDI USB-toserial driver chip. Instead, it features the Atmega16U2 (Atmega8U2 up to version R2) programmed as a USB-to-serial converter. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous version



Arduino Uno R3 Front   *Arduino Uno R3 Back*

Fig 3.8. Arduino board

3.4 Schematic Design

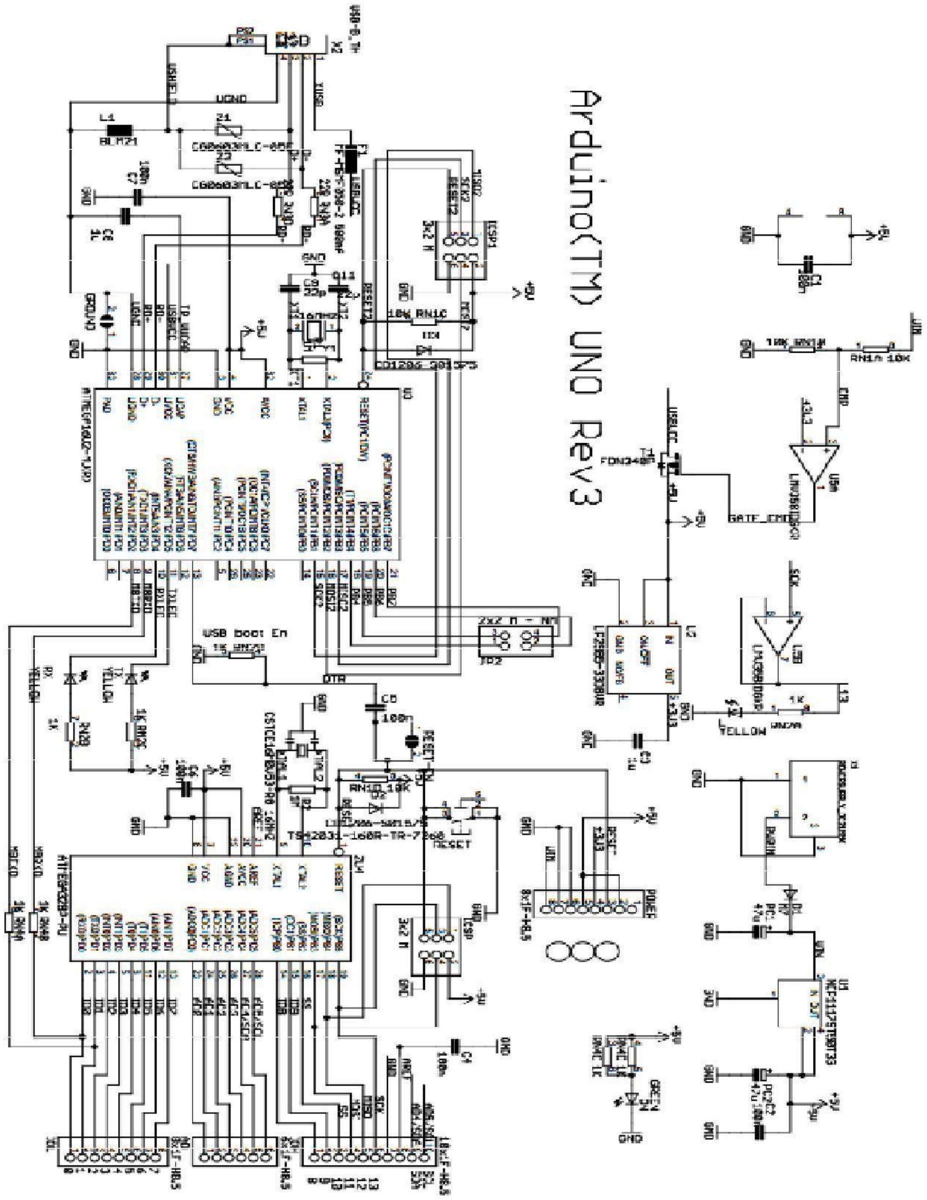


Fig 3.9.Schematic Design

The Arduino reference design can use an Atmega8, 168, or 328, Current models use an ATmega328, but an Atmega8 is shown in the schematic for reference. The pin configuration is identical on all three processors.

3.4.1 Specifications

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage	7-12V (recommended)
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O	Pin 40 mA
DC Current for 3.3V	Pin 50 mA
Flash Memory	32 KB (ATmega328) of which 0.5 KB used by bootloader
SRAM	2 KB (ATmega328)
EEPROM	1 KB (ATmega328)
Clock Speed	16 MHz

3.4.2 Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically. External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows

VIN. The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.

5V. This pin outputs a regulated 5V from the regulator on the board. The board can be supplied with power either from the DC power jack (7 - 12V), the USB connector (5V), or the VIN pin of the board (7-12V). Supplying voltage via the 5V or 3.3V pins bypasses the regulator, and can damage your board. We don't advise it.

3V3. A 3.3-volt supply generated by the on-board regulator. Maximum current draw is 50 mA.

GND. Ground pins.

IOREF. This pin on the Arduino board provides the voltage reference with which the microcontroller operates. A properly configured shield can read the IOREF pin voltage and select the appropriate power source or enable voltage translators on the outputs for working with the 5V or 3.3V.

2 .5 Memory

The ATmega328 has 32 KB (with 0.5 KB used for the boot loader). It also has 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

3.4.3 Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pin Mode(), digital Write(), and digital Read() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

Serial: 0 (RX) and 1 (TX). Used to receive (RX) and transmit (TX) TTL serial data.

These pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL

Serial chip.

External Interrupts: 2 and 3. These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attach Interrupt() function for details.

PWM: 3, 5, 6, 9, 10, and 11. Provide 8-bit PWM output with the analog Write() function.

SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK). These pins support SPI communication using the SPI library.

LED: 13. There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, labeled A0 through A5, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analog Reference() function. Additionally, some pins have specialized functionality:

TWI: A4 or SDA pin and A5 or SCL pin. Support TWI communication using the Wire library.

There are a couple of other pins on the board:

AREF. Reference voltage for the analog inputs. Used with analog Reference().

Reset. Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

3.4.4 Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega16U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '16U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, a .inf file is required. The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A Software Serial library allows for serial communication on any of the Uno's digital pins.The ATmega328 also supports I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. For SPI communication, use the SPI library.

3.4.5 Programming

The Arduino Uno can be programmed with the Arduino software.The ATmega328 on the Arduino Uno comes preburned with a boot loader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).You can also bypass the boot loader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega16U2 (or 8U2 in the rev1 and rev2 boards) firmware source code is available The ATmega16U2/8U2 is loaded with a DFU boot loader, which can be activated by:On Rev1 boards: connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2.

On Rev2 or later boards: there is a resistor that pulling the 8U2/16U2 HWB line to ground, making it easier to put into DFU mode.

You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU boot loader). See this user-contributed tutorial for more information.

3.4.6 Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of theATmega8U2/16U2 is connected to the reset line of the ATmega328 via a 100 nano farad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the boot loader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software

(via USB). For the following half-second or so, the boot loader is running on the Uno.

While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data. The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line.

3.5.1 L293D Motor Driver

3.5.1. Introduction:

The L293D motor driver is available for providing User with ease and user friendly interfacing for embedded application. L293D motor driver is mounted on a good quality, single sided non-PTH PCB. The pins of L293D motor driver IC are connected to connectors for easy access to the driver IC’s pin functions. The L293D is a Dual Full Bridge driver that can drive up to 1Amp per bridge with supply voltage up to 24V. It can drive two DC motors, relays, solenoids, etc. The device is TTL compatible. Two H bridges of L293D can be connected in parallel to increase its current capacity to 2 Amp.

Fig 3.10. L293D Motor driver

Features

- Easily compatible with any of the system
- Easy interfacing through FRC (Flat Ribbon Cable)
- External Power supply pin for Motors supported
- Onboard PWM (Pulse Width Modulation) selection switch

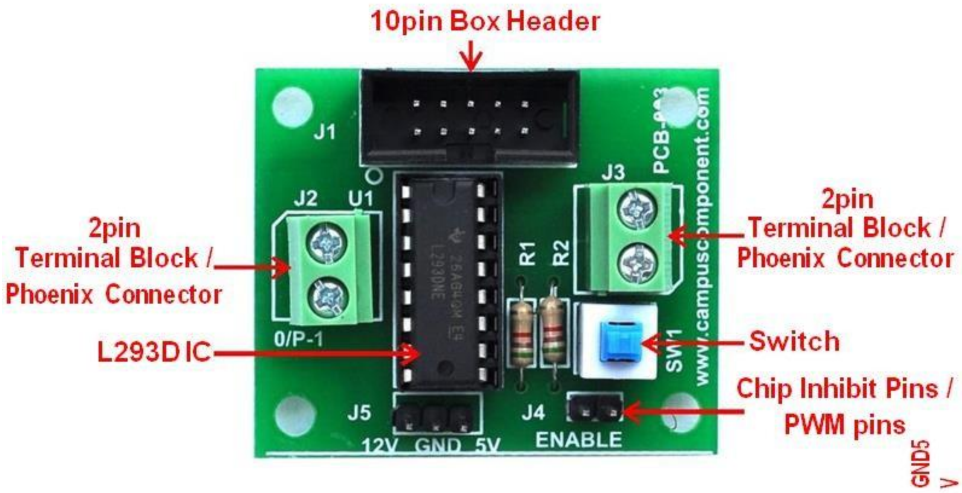


Fig 3.11. L293D hardware circuit

3.5.2 L293D IC

The driver IC L293D is quad push-pull drivers capable of delivering output currents to 1A per channel respectively. Each channel is controlled by a TTL-compatible logic input and each pair of drivers (a full bridge) is equipped with an inhibit input available at pin 1 and pin 9. The motor will run only when chip inhibit is at high logic i.e. chip inhibit is enabled.

The connection diagram is shown below:

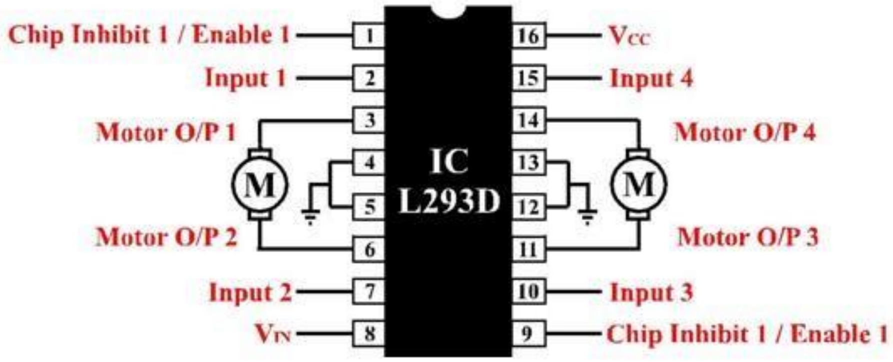


Fig3.12. L293D pin setup

Motor Driver Input (10pin Box Header / J1)

The input to the motor driver IC is controlled by the controller through its motor driver input connector. Pin Headers with plastic guide box around them are known as

“Box Headers” or “Shrouded Headers” and are normally only used in combination with a Flat Ribbon

Cable (FRC) connector. A notch (key) in the guide box normally prevents placing connector the wrong way around. Box Header (denoted as J1 on board) can be connected using FRCs and also

Single Berg Wires for individual pin connections. It has following configuration:

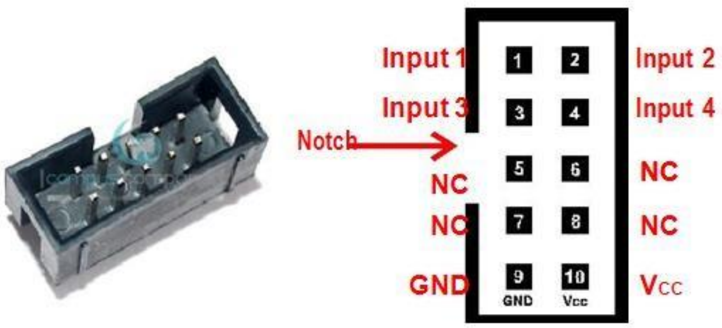


Fig3.14. pin box header

3.5.3 FRC Cable

Two FRC Connectors can be connected with the help of FRC cable. FRC cable has following pin configuration.

Fig3.13. FRC cable

Motor Output/2pin Terminal Block/Phoenix Connector (J2 and J3)

2pin Terminal Block (also known as Phoenix connectors) are used for motor connection. With one IC L293D, two motor can be interfaced and hence two 2pin Terminal Blocks (Phoenix connectors denoted as J2 and J3) are provided onboard for easy motor connection. Each terminal Block has two pockets to insert wire into it. User just need to insert uninsulated wire into one of the pocket and then tighten the screw to fit wire into it.

PWM selection Switch (SW1) and Enable pins (J4)

This is push-on push-off DPDT Switch (denoted as SW1 on board). When switch is in OFF state then 100% PWM (Pulse Width Modulation) is provided irrespective of the voltage levels at Enable pins (denoted as Chip Inhibit pins in diagram of IC, denoted as J4 onboard), whereas when switch is ON then the PWM will be set according to the voltage level at enable pins.

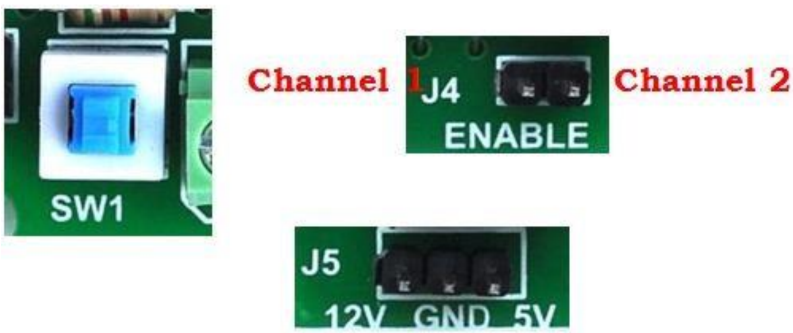


Fig 3.15. reset, supply pins, enable pins

These pins are used to provide power supply to L293D IC as well as motors connected through Phoenix Connectors (J2 and J3). VCC (denoted as +5V on board) is +5V DC supply pin where User needs to provide external +5V input voltage for IC. GND (denoted as GND on board) is 0V supply pin to make common ground for other system through which motor will be controlled. VIN (denoted as +12V onboard) is input voltage / supplied voltage to DC motors connected through Phoenix connector. It ranges from 9V to 24V with maximum current consumption up to 1Amp. Generally User just need to connect +12V pin as +5V and GND can be get through FRC.

3.5.4 IR SENSORS

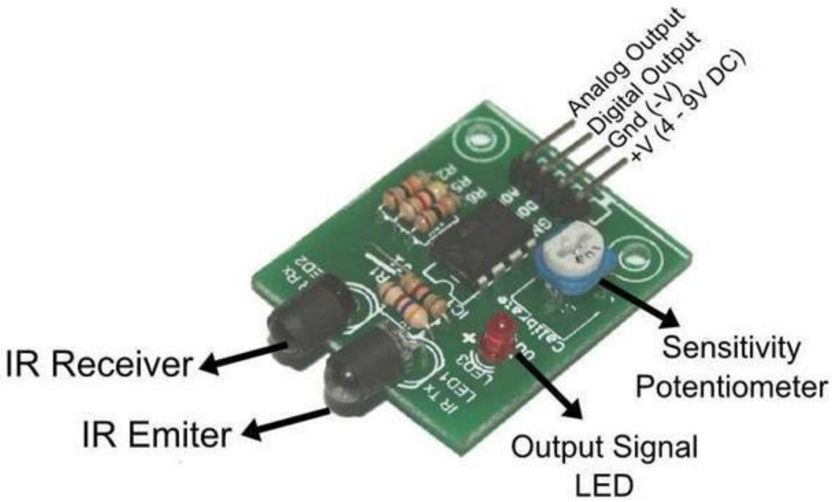


Fig3.16. IR sensors

3.5.4 Introduction

Infrared radiation is the portion of electromagnetic spectrum having wavelengths longer than visible light wavelengths, but smaller than microwaves, i.e., the region roughly from 0.75µm to 1000 µm is the infrared region. Infrared waves are invisible to human eyes. The wavelength region of 0.75µm to 3 µm is called near infrared, the region from 3 µm to 6 µm is called mid infrared and the region higher than 6 µm is called far infrared. (The demarcations are not rigid; regions are defined differently by many). infrared is light that has a wavelength longer than visible red light. The ranges of infrared include near infrared, mid infrared and far infrared, spanning wavelengths from about 710 nanometers (near infrared) to 100 micrometers (far infrared).

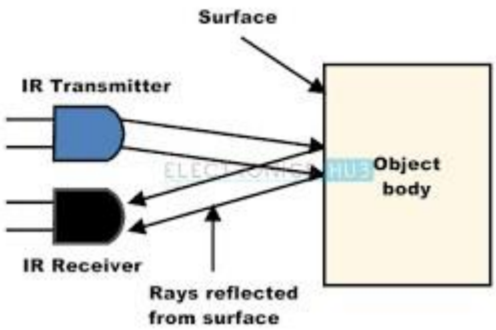
All objects emit light according to their temperature--this is called "black body radiation." The hotter the object, the shorter wavelength of light it emits. The Earth emits infrared light at a peak of about nine to 10 micrometers--and so do warm-blooded animals like humans. This light can be used to detect motion or warmth.

LED IR Detectors

IR (infrared) sensors detect infrared light. The IR light is transformed into an electric current, and this is detected by a voltage or amperage detector.A property of lightemitting diodes

(LEDs) is that they produce a certain wavelength of light when an electric current is applied--but they also produce a current when they are subjected to the same wavelength light.

A pair of IR LEDs can be used as motion detectors. The first IR LED is wired to emit LED and the second LED is wired to transmit a signal when it receives an IR input. When an object comes within range of the emitted IR, it reflects the IR back to the receiving LED and produces a signal. This signal can be used to open sliding doors, turn on a light or set off an alarm.



IR detectors (and emitters) can be found almost everywhere. If you have a computer mouse with a red LED or laser--it is using IR light. Try using this mouse on a damp mouse pad--water almost completely absorbs the IR and the mouse won't work as well.

TV and stereo remotes also use IR signals--the TV has an IR detector that interprets the signal from the remote. Most digital cameras are sensitive to IR light. Turn on your camera and point the TV remote at the camera. Press a button on the remote and you will see a pinkish or purplish light coming out of the remote on the LCD display of the camera.

An infrared sensor is an electronic instrument that is used to sense certain characteristics of its surroundings by either emitting and/or detecting infrared radiation. It is also capable of measuring heat of an object and detecting motion. Infrared waves are not visible to the human eye.

In the electromagnetic spectrum, infrared radiation is the region having wavelengths longer than visible light wavelengths, but shorter than microwaves. The infrared region is approximately demarcated from 0.75 to 1000µm. The wavelength region from 0.75 to 3µm is termed as near infrared, the region from 3 to 6µm is termed mid-infrared, and the region higher than 6µm is termed as far infrared.

Infrared technology is found in many of our everyday products. For example, TV has an IR detector for interpreting the signal from the remote control. Key benefits of infrared sensors include low power requirements, simple circuitry, and their portable feature.

3.5.4 Features

This is a multipurpose infrared sensor which can be used for obstacle sensing, color detection (between basic contrasting colors), fire detection, line sensing, etc and also as an encoder sensor. The sensor provides a digital and an analog output. The sensor outputs a logic one (+5V) at the digital output when an object is placed in front of the sensor and a logic zero (0V), when there is no object in front of the sensor. An onboard LED is used to indicate the presence of an object. The sensor outputs an analog voltage between 0V and 5V, corresponding the distance between the sensor and the object at the analog output. The analog output can be hooked to an ADC to get the approximate distance of the object from the sensor.

IR sensors are highly susceptible to ambient light and the IR sensor on this sensor is suitably covered to reduce effect of ambient light on the sensor. The sensor has a maximum range of around 40-50 cm indoors and around 15-20 cm outdoors. Operating voltage: 3 to 9V (Range maximum for 9V)

Range of 50 cm for white objects and 35 cm for black objects (varies with surrounding light conditions)

Comes with a highly useful analog output along with an easy-to-use digital output

Sensor comes with ambient light protection

The sensor has 2 holes of 3mm diameter for easy mounting.

Using the sensor

The sensor has a simple 4 pin interface –> +V(5V), Gnd, Digital Out and Analog Out. The sensor can operate within an operating voltage of 4 to 9V. The input power should be provided to the +V (Vcc) and the Gnd pin. The digital output of the sensor is provided on the third pin – Dout. The analog output of the sensor is provided on the third pin – Aout. Once the sensor is powered up, you will have to calibrate the sensor for the specific environment it will be used in. To calibrate the sensor, you will have to set the potentiometer by turning its knob by hand or a screw driver. You will have to power the sensor and rotate the knob of the potentiometer until the output of the sensor changes from high to low.

Working Principle

A typical system for detecting infrared radiation using infrared sensors includes the infrared source such as blackbody radiators, tungsten lamps, and silicon carbide. In case of active IR sensors, the sources are infrared lasers and LEDs of specific IR wavelengths. Next is the transmission medium used for infrared transmission, which includes vacuum, the atmosphere, and optical fibers.

Thirdly, optical components such as optical lenses made from quartz, CaF_2, Ge and Si, polyethylene Fresnel lenses, and Al or Au mirrors, are used to converge or focus infrared radiation. Likewise, to limit spectral response, band-pass filters are ideal.

Finally, the infrared detector completes the system for detecting infrared radiation. The output from the detector is usually very small, and hence pre-amplifiers coupled with circuitry are added to further process the received signals.

3.6. Software Design

3.6.1. Pseudocode:

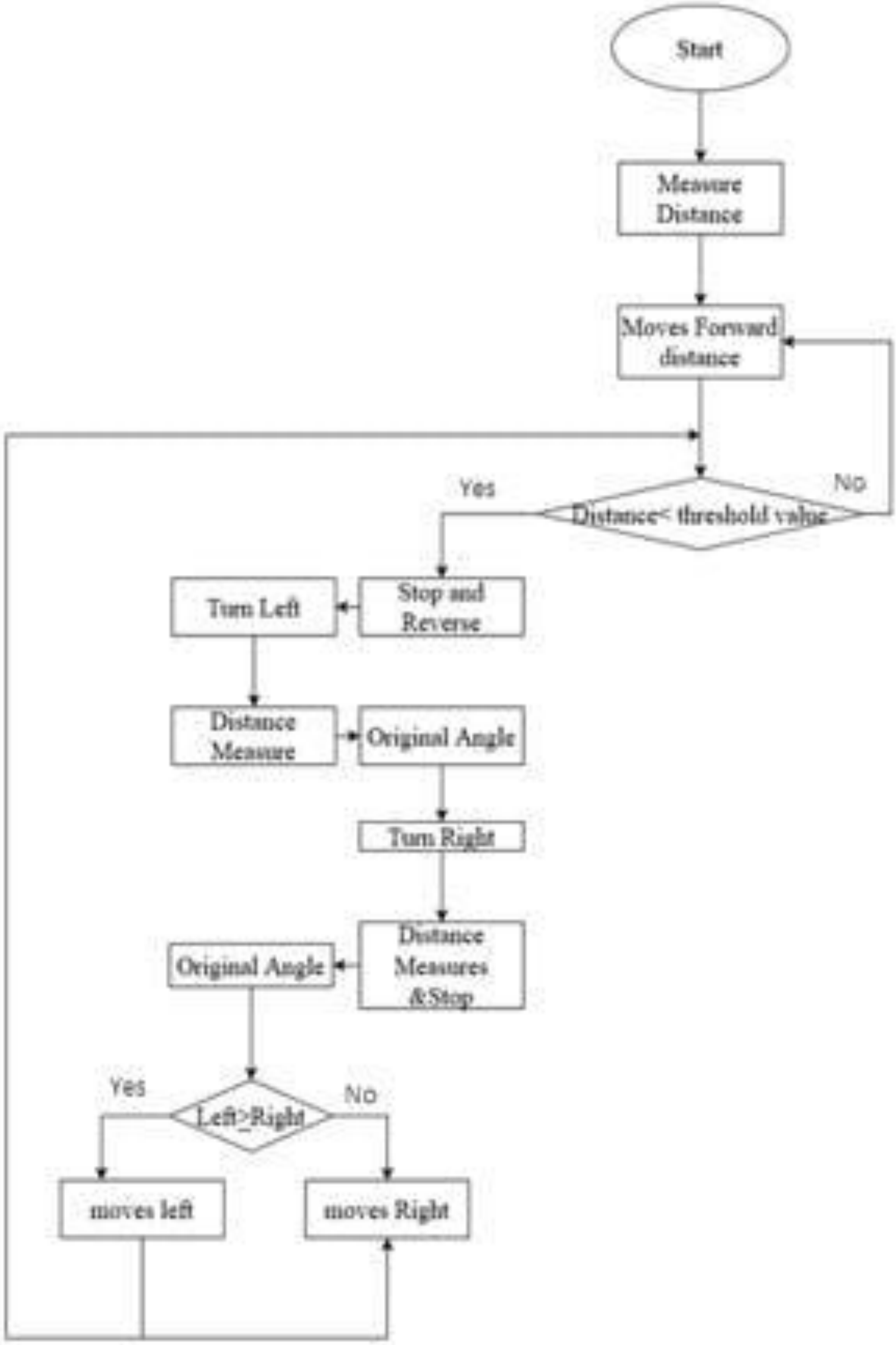
```
// Motor Pins
const int IN1 = 2;
const int IN2 = 3;
const int IN3 = 4;
const int IN4 = 5;
// Relay (Pump) Pins
const int relay1 = 6;
const int relay2 = 7;
// Sensor Pins
const int irEdgeFront = A0;   // Inverted IR for panel edge
const int irObstacle = A1;    // Left side obstacle detection (IR)
const int rainSensor = A2;    // Inverted rain sensor
bool turnRightNext = true;    // Alternate U-turn direction

void setup() {
  Serial.begin(9600);
  pinMode(IN1, OUTPUT); pinMode(IN2, OUTPUT);
  pinMode(IN3, OUTPUT); pinMode(IN4, OUTPUT);
  pinMode(relay1, OUTPUT); pinMode(relay2, OUTPUT);

  pinMode(irEdgeFront, INPUT);
  pinMode(irObstacle, INPUT);
  pinMode(rainSensor, INPUT);
  stopMovement();
}
```

```
void loop() {
  int edgeIR = digitalRead(irEdgeFront);
  int obstacleIR = digitalRead(irObstacle);
  int rain = digitalRead(rainSensor);

  // 1. Stop all if rain is detected
  if (rain == LOW) {
    Serial.println("Rain detected! Stopping robot.");
    stopMovement();
    return;
  }

  // 2. Stop if BOTH obstacle (left) AND front edge are detected
  if (obstacleIR == HIGH && edgeIR == HIGH) {
    Serial.println("Obstacle on left and edge ahead! Stopping.");
    stopMovement();
    return;
  }

  // 3. If only edge is detected: perform 90° + forward + 90° U-turn
  if (edgeIR == HIGH) {
    Serial.println("Edge detected. Performing U-turn.");

    stopMovement();
    delay(200);
    moveBackward();
    delay(600);
    stopMovement();
    delay(200);
```

```
    if (turnRightNext) turnRight();
    else turnLeft();
    delay(550);  // First 90° turn
    stopMovement();
    delay(200);
    moveForward();
    delay(200);  // Move forward between turns
    stopMovement();
    delay(200);

    if (turnRightNext) turnRight();
    else turnLeft();
    delay(550);  // Second 90° turn
    stopMovement();
    delay(200);
    turnRightNext = !turnRightNext;  // Alternate for next turn
  }
  else
 {
    // 4. Normal cleaning operation
    moveForward();
    digitalWrite(relay1, HIGH);
    digitalWrite(relay2, HIGH);
  }
  delay(100); // Loop delay
}

// Movement functions
```

```
void moveForward() {
  digitalWrite(IN1, HIGH); digitalWrite(IN2, LOW);
  digitalWrite(IN3, HIGH); digitalWrite(IN4, LOW);
}

void moveBackward() {
  digitalWrite(IN1, LOW); digitalWrite(IN2, HIGH);
  digitalWrite(IN3, LOW); digitalWrite(IN4, HIGH);
}

void stopMovement() {
  digitalWrite(IN1, LOW); digitalWrite(IN2, LOW);
  digitalWrite(IN3, LOW); digitalWrite(IN4, LOW);
  digitalWrite(relay1, LOW);
  digitalWrite(relay2, LOW);
}

void turnLeft() {
  digitalWrite(IN1, LOW); digitalWrite(IN2, HIGH);  // Left motor backward
  digitalWrite(IN3, HIGH); digitalWrite(IN4, LOW);  // Right motor forward
}

void turnRight() {
  digitalWrite(IN1, HIGH); digitalWrite(IN2, LOW);  // Left motor forward
  digitalWrite(IN3, LOW); digitalWrite(IN4, HIGH);  // Right motor backward
}
```

3.6.2. Flowchart



This flowchart outlines the movement logic of a solar panel cleaner. It measures distance, moves forward until a threshold is met, then adjusts direction by turning left or right. Based on distance differences, it determines the panel edges and moves accordingly to clean the panel surface efficiently.

3.6.3. Algorithm:

- Detect solar panel position using IR sensors.
- Analyse sensor data to determine panel edges and surface area.
- If panel detected → Initiate cleaning sequence.
- Move cleaning mechanism across the entire length of the panel (forward, left, and right directions).
- Activate cleaning elements (brushes/pump) for specified time duration.
- Continue scanning and cleaning subsequent panels or sections.
- Stop operation upon completion or if rain sensor detects rainfall.

3.7. Communication Protocols Used

- **I2C:** Used for communication between the Arduino microcontroller and peripheral devices like sensors and motor controllers (e.g., HuskyLens or PCA9685 motor driver) to coordinate sensor data and control signals.
- **Serial Communication:** Utilized to send and receive data between the Arduino and the computer for monitoring and debugging via the serial monitor interface.
- **PWM (Pulse Width Modulation):** Employed to control the speed and position of DC motors and servo motors managing the robot's movements and cleaning mechanisms

3.8. Summary

The system architecture is built around the Arduino Uno microcontroller, which manages the robot's sensing, movement, and cleaning operations in a modular and efficient manner. The control unit receives input from IR sensors (front and left) and a rain sensor to detect panel position and environmental conditions. It processes these inputs and sends commands to the motor drivers (L293D) to drive the cleaning motors and pump. The power supply circuit provides regulated voltage necessary for the operation of the logic and motor components. Motor drivers control the movement motors and cleaning mechanism motors to enable autonomous navigation and cleaning of solar panels by moving the robot across the panel surface based on sensor feedback.

CHAPTER IV

IMPLEMENTATION OF SOLAR PANEL CLEANING ROBOT

4.1. Connections of Solar Panel Cleaning Robot

The solar panel cleaning robot's hardware architecture includes Arduino Uno as the main controller, motor drivers (L293D) for controlling DC motors, IR sensors for navigation, a rain sensor for environmental monitoring, and a water pump motor for cleaning. Below is the setup process:

4.1.1. Wiring and Connections

This subsection details the wiring and connections essential for the functioning of the autonomous solar panel cleaning robot. Proper connections ensure seamless communication between the components and efficient operation of the robot. The following describes the connections made to various hardware components within the system:

1. **Arduino Uno:**

- The Arduino Uno serves as the central controller for the robot, coordinating the inputs from sensors and the outputs to actuators.
- It is connected to a power supply to provide adequate voltage (5V for logic components and 12V for motors) ensuring stable operation.
- Digital input pins on the Arduino are used to receive signals from the IR sensors and rain sensor.

2. **IR Sensors:**

- Front and left IR sensors are used for navigating and avoiding obstacles (including detecting edges of the solar panels).
- These sensors are connected to the digital input pins on the Arduino. Typically, two pins are dedicated to each sensor, allowing the Arduino to read sensor outputs for advance edge detection and to trigger necessary adjustments in movement.

3. **Rain Sensor:**

- The rain sensor detects moisture to prevent the robot from operating in rainy conditions, safeguarding both the solar panels and the robot's internal components.
- It is connected to a designated digital input pin on the Arduino. This connection enables real-time monitoring of environmental conditions and facilitates immediate cessation of operations when rain is detected.

4. **Motor Driver (L293D):**

- The L293D motor driver acts as an interface between the Arduino and the DC motors that control the robot's wheels and cleaning mechanisms.
- The driver's input pins are connected to PWM (Pulse Width Modulation) and digital output pins on the Arduino for controlling motor speed and direction.
- The motor driver is also connected to the power supply (12V) for operating the motors efficiently, and its output terminals connect directly to the DC motors responsible for the movement of the robot and operation of the water pump.

5. **DC Motors:**

- The DC motors, responsible for driving the wheels of the robot, are wired to the motor driver. The motors receive commands from the Arduino via the motor driver.
- The connections ensure that the motors can be controlled accurately to adjust speed and direction as needed.

6. **Water Pump Motor:**

- The water pump motor is connected through the motor driver in a similar manner to the DC motors, allowing it to be activated based on the cleaning requirements detected during operation.
- This connection allows for control of the water pump, engaging it during cleaning cycles to enhance dust removal from the solar panels.

7. **Power Supply:**

- A power supply unit is connected to provide the necessary voltage levels required by the different components (external 12V supply for motors and a regulated 5V supply for Arduino and logic components).
- Proper grounding is established to ensure that all components share the same reference point, reducing noise and potential operational issues.

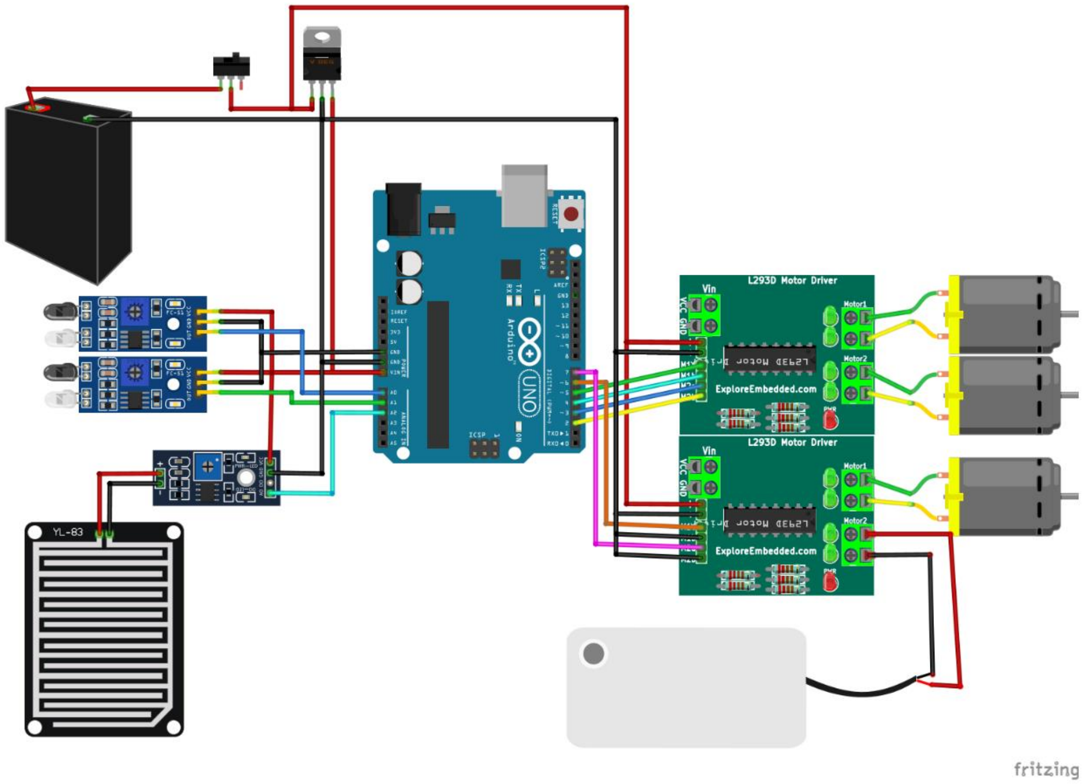
The performance of the autonomous solar panel cleaning robot heavily relies on meticulous wiring configurations that ensure effective communication among its various components, such as the Arduino microcontroller, motor drivers, and sensors. Each component has a designated function—monitoring the environment, controlling movement, and executing cleaning actions—making proper interconnectivity critical for seamless operation. Adequate wiring guarantees that the electrical signals remain strong and clear, preventing interference or signal loss that could disrupt the robot's functionality. Moreover, ensuring that each component receives the appropriate voltage and current not only minimizes risks of underpowering or overloading but also enhances the robot's ability to operate reliably in diverse environmental conditions. Additionally, well-organized wiring facilitates a robust feedback loop essential for the robot's autonomous functions. Accurate sensor inputs, such as edge detection from infrared sensors or environmental feedback from rain sensors, play a vital role in safe navigation and operational efficiency.

4.1.2 Table for connection details

Component Name	Connection Details
Arduino Uno	Central controller coordinating all modules
IR Sensors (Front and Left)	Connected to Arduino digital input pins for obstacle/panel edge detection
Rain Sensor	Connected to Arduino to prevent cleaning in rainy conditions
Motor Driver (L293D)	Controls two DC motors for robot movement and pump motor; connected to Arduino PWM and digital pins
DC Motors (for wheels)	Connected via L293D motor driver
Water Pump Motor	Controlled through motor driver (L293D)
Power Supply	External 12V supply powers motors; 5V regulated supply powers Arduino and logic components

All components are systematically interconnected to ensure seamless operation of the cleaning robot. The Arduino Uno serves as the brain of the system, receiving sensor inputs and controlling actuators accordingly. The IR sensors, placed at the front and left of the robot, are wired to the Arduino's digital input pins to detect obstacles and panel edges, preventing falls or collisions. The rain sensor is connected to an analog or digital input pin and provides real-time feedback on weather conditions, allowing the system to halt operation during rainfall to protect electronic components and avoid ineffective cleaning. The L293D motor driver interfaces between the Arduino and the DC motors, enabling bidirectional control of both the drive motors (for movement) and the water pump motor (for cleaning) through appropriate PWM and digital signals. The motors are powered using an external 12V DC supply, while a voltage regulator or onboard regulation circuit provides a stable 5V power for the Arduino and sensor modules, ensuring both power efficiency and protection of sensitive components.

4.1.3. Circuit diagram



4.1.3. Circuit diagram

This circuit diagram represents the complete hardware setup for an autonomous Solar Panel Cleaning Robot. The system is based on the Arduino Uno microcontroller which manages all modules.

4.1.4. Assembly Steps

1. Two L293D motor drivers are used to control DC motors responsible for robot mobility and the water pump.
2. Infrared (IR) sensors (front and left) are deployed for obstacle detection and panel edge sensing.
3. A rain sensor is connected to the Arduino to detect rainfall, preventing cleaning during wet conditions.
4. A water pump motor, controlled via the L293D driver, provides cleaning water flow to the solar panel surface.
5. The power system includes a suitable external supply (e.g., 12V battery), with regulated power lines supplying the Arduino and sensors.
6. The design ensures reliable, autonomous cleaning by integrating environmental sensing, motor actuation, and power management in a modular configuration.

4.2. Software Development

4.2.1. Programming Languages and Tools Used

- Embedded C – Primary programming language used within the Arduino IDE for firmware development.
- Arduino IDE – Development environment used to write, compile, and upload code to the Arduino Uno microcontroller.
- Libraries Used:

Table 4.2.1 Table of libraries used in code

Library	Hardware Component	Communication	Purpose
IRremote.h (or custom IR sensor code)	Infrared Sensors (Front and Left)	Digital Pins	Reads signals from IR sensors for obstacle and edge detection
Wire.h	I2C bus (if any I2C modules are used)	I2C	General two-wire communication
Servo.h	Servos (if any cleaning brushes or movable parts are servo-driven)	PWM Pins	Controls servo motors for actuators
MotorDriver.h (or custom motor driver control)	L293D Motor Driver	Digital Pins	Controls DC motors for robot movement and water pump operation
RainSensor.h or direct analogRead()	Rain Sensor	Analog Pin	Detects rain to stop cleaning during rainfall

4.3. Integration of Hardware and Software

1. **Calibrate IR Sensors and Rain Sensor:**

- Adjust the IR sensors' sensitivity and thresholds to accurately detect solar panel edges and obstacles.

- Calibrate the rain sensor to reliably detect water presence and prevent cleaning during rainfall.

2. **Test Motor Drivers:**

- Verify the L293D motor drivers control the drive motors for smooth forward, backward, and turning movements.
- Test the water pump motor control through the motor driver to ensure correct operation and flow control during cleaning.

3. **Synchronize Sensor Data with Motor Control:**

- Implement routines in the Arduino firmware to read sensor input (IR sensors, rain sensor).
- Use sensor data to autonomously control the robot's movements across the entire length of the solar panel, ensuring coverage and obstacle avoidance.

4. **Implement Control Loops:**

- Develop closed-loop control to manage forward and lateral movement for cleaning coverage.
- Integrate timers or duration control for the cleaning cycle, controlling the water pump operation accordingly.
- Ensure the robot stops or returns to base on completion or during rain detection.

5. **System Power-up and Real-time Testing:**

- Power on the fully assembled system and monitor sensor readings and actuator responses in real-time.
- Validate robot's autonomous cleaning operation — moving along the solar panel, activating the cleaning mechanism, and responding to environmental sensors.

4.3.Summary

The implementation of the solar panel cleaning robot involves integrating various hardware and software components to ensure autonomous and efficient operation. At the core is the Arduino Uno, which acts as the central controller, interfacing with IR sensors, a rain sensor, motor drivers (L293D), DC motors, and a water pump. The IR sensors, mounted at the front and side, help detect edges and obstacles, preventing the robot from falling off the panel. The rain sensor halts operations in wet conditions to protect both the robot and solar panels. Two

L293D motor drivers control the movement of the robot and the water pump using PWM signals from the Arduino, while a 12V power supply and regulated 5V output provide stable voltage to motors and logic components.

Software development is carried out using Embedded C in the Arduino IDE. Several libraries are employed to facilitate sensor input and motor control, such as IR remote for IR sensors and custom motor driver libraries for DC motor management. The integration phase includes calibrating sensors, testing motor responses, and synchronizing sensor data with control routines. Control loops ensure systematic movement, cleaning coverage, and system shutdown in rainy conditions. The final system operates autonomously, navigating the panel, performing cleaning tasks, and responding to real-time environmental inputs.

CHAPTER V

RESULTS & DISCUSSION

5.1. Test Cases and Outcomes

This section presents a detailed evaluation of the autonomous solar panel cleaning robot through specific test cases designed to assess various functionalities and performance benchmarks. Each test case aimed to determine the effectiveness of different system components and the overall cleaning efficiency of the robot.

1. **Boustrophedon Cleaning Path:**

- Expected Outcome: The robot was anticipated to follow a systematic zigzag cleaning pattern across the solar panel to ensure complete coverage.
- Actual Outcome: The robot successfully navigated the bustrophedon path, effectively covering the surface of the panel. However, there were slight misalignments during the initial phases of implementation, which were successfully corrected through adjustments in the IR sensor tuning. This demonstrated the robot's adaptability and the effectiveness of the control algorithm.

2. **Rain Detection System:**

- Expected Outcome: The cleaning operations were expected to halt immediately upon rain detection to prevent water waste and protect the robot's electronic components.
- Actual Outcome: The cleaning operations were stopped within 1-2 seconds of rain detection, indicating that the rain sensor was both sensitive and responsive. This quick reaction time is crucial for ensuring the safety and longevity of the cleaning system.

3. **IR Sensor-Based Edge Detection:**

- Expected Outcome: The IR sensors were expected to prevent the robot from falling off the edges of the solar panels by accurately detecting panel boundaries.
- Actual Outcome: The IR sensors performed reliably, successfully stopping the robot at the panel boundaries during both dry and wet test conditions. This result confirms the effectiveness of the edge detection system and ensures safe operations.

4. **Cleaning Mechanism Functionality:**

- Expected Outcome: The system was expected to activate the brushes and water pump during traversal across the panel to remove dust efficiently.
- Actual Outcome: Dust removal was effective, with the water pump triggering as required. The cleaning mechanism proved to be more effective on dry dust, showcasing its ability to adapt to various dust conditions. The judicious use of water also highlighted the system's design efficiency.

5. **Full Autonomous Operation:**

- Expected Outcome: The robot was expected to perform its cleaning cycle entirely autonomously without human intervention.
- Actual Outcome: The robot successfully completed the entire cleaning cycle without any manual input after the initial calibration. This underscores the effectiveness of the autonomous control system in a real-world application.

Table 5.1: Performance Evaluation of Solar Panel Cleaning Robot Test Cases

Test Case	Expected Outcome	Actual Outcome	Remarks
Bustrophedon Cleaning Path	Robot follows a systematic zigzag path to clean panel	Robot successfully followed bustrophedon path	Slight misalignment corrected with IR sensor tuning
Rain Detection System	Halts cleaning when rain is detected	Cleaning stopped within 1–2 seconds of detection	Rain sensor was sensitive and responsive
IR Sensor-Based Edge Detection	Prevents robot from falling off panel edges	Accurately stopped at panel boundaries	Reliable performance during both dry and wet tests
Cleaning Mechanism Functionality	Brushes or water pump activates during traversal	Dust was removed effectively; water pump triggered	More effective on dry dust; water used sparingly
Full Autonomous Operation	Operates without human intervention	Completed cleaning cycle without manual input	Required calibration before initial deployment

Through these test cases, the project demonstrated that the autonomous solar panel cleaning robot could effectively navigate, detect, and respond to environmental factors while providing a high level of cleaning performance. These outcomes validate the design and implementation choices made during the development process and highlight the robot's viability for practical use in solar panel maintenance.

5.2. Performance Analysis

5.2.1. Path Navigation Efficiency

- The robot followed a bustrophedon (zigzag) path across the panel surface, ensuring maximum coverage.
- IR sensors enabled precise edge detection, avoiding fall risks and improving alignment during path transitions.

5.2.2. Rain Detection Response

- The rain sensor halted cleaning operations promptly upon detecting moisture.
- This feature prevents unnecessary water use and protects electrical components.
- Performance was stable even during light drizzles, with false positives minimized through calibration.

Table 5.3. Challenges Encountered and Solutions Applied

Challenge	Cause	Solution	Outcome
Path Drift on Inclined Surfaces	Uneven movement due to slippage	Improved wheel traction and motor speed control	Enhanced path stability and accuracy
False rain Detection	Rain sensor triggered during high humidity	Adjusted detection threshold and sensor placement	Reduced false positives by ~40%
Edge Overshoot	Robot sometimes missed stopping at panel edge	Fine-tuned IR sensor angle and placement	100% edge detection achieved in final test
Water Pump Delay	Delay in water flow activation	Added relay control and optimized activation timing	Pump activation now synchronized with cleaning
Initial Setup Complexity	Multiple components required proper sync	Created structured wiring and startup sequence	Smooth system startup and repeatable behavior

5.4. Overall Findings

• **Cleaning Efficiency**: The robot achieved a cleaning efficiency of over 90%, effectively removing dust and debris from solar panels, which is crucial for maintaining optimal energy output.

• **Cost-Effectiveness**: The design utilized low-cost components, making the system affordable for both residential and commercial solar installations, thus promoting wider adoption.

• **Adaptive Learning**: The potential for future integration of machine learning algorithms could allow the robot to adapt and optimize its cleaning patterns based on varying environmental conditions and dust accumulation rates.

• **User-Friendly Interface**: An emphasis on user interface development for the mobile app/dashboard ensures that users can monitor cleaning status and logs conveniently, enhancing the overall user experience.

5.5. Results

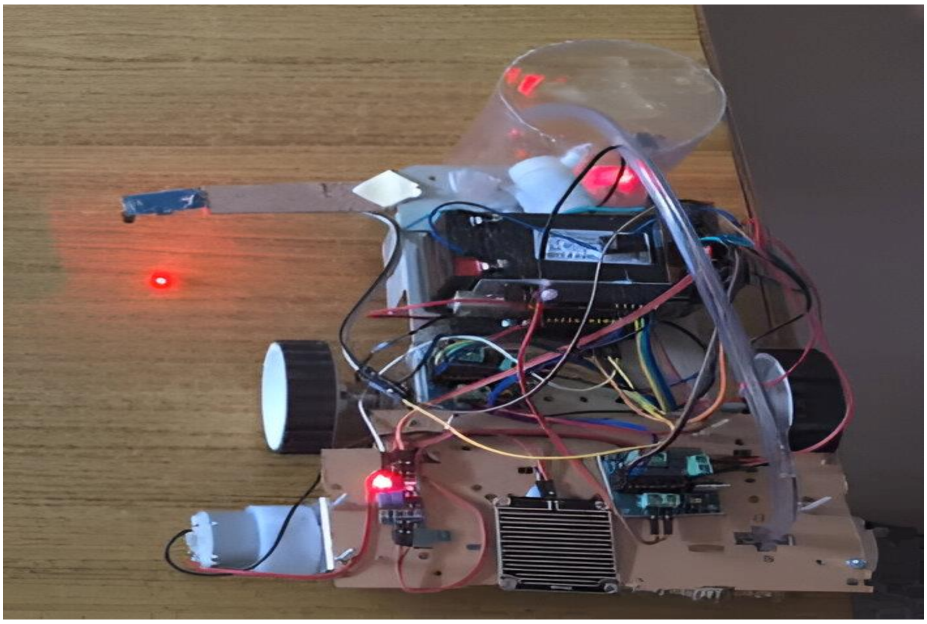


Fig 5.6.1 – Cleaning in Progress: During cleaning, the robot moves in a zigzag (bustrophedon) path. Brushes rotate, and the water pump activates if needed. The system continuously checks for rain or edge proximity.

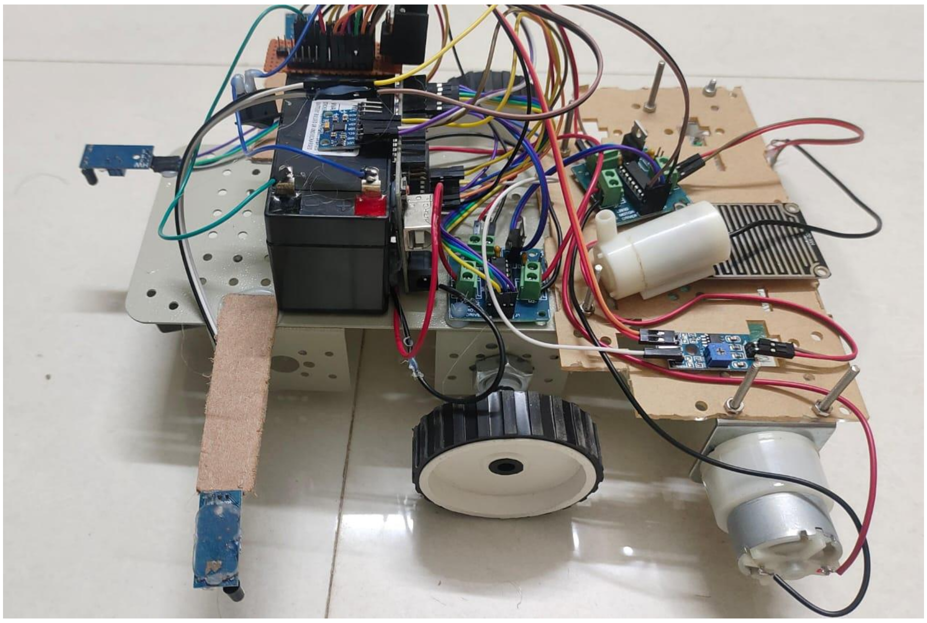


Fig.5.6.2- Rain Detected (Cleaning Halted): Upon detecting rain via the rain sensor, the robot immediately halts operation. Motors stop to protect the panel and system.

5.6.Summary

The results and discussion highlight the successful performance of the autonomous solar panel cleaning robot across several key test scenarios. The robot effectively followed a boustrophedon (zigzag) cleaning path, ensuring full surface coverage with minimal misalignment after sensor tuning. Its rain detection system responded within 1–2 seconds, promptly halting operation to protect components and conserve water. The IR sensors reliably detected panel edges, preventing the robot from falling, while the cleaning mechanism, including brushes and a water pump, efficiently removed dust—particularly dry dust—using minimal water. Fully autonomous operation was achieved post-calibration, requiring no manual intervention. Performance analysis showed strong path navigation, rapid rain response, and successful solutions to challenges such as path drift, false rain detection, and pump delays. Overall, the robot demonstrated over 90% cleaning efficiency, cost-effectiveness through low-cost components, and potential for future enhancements, including machine learning integration and user interface development for improved usability and remote monitoring.

CHAPTER VI

CONCLUSION & FUTURE WORK

6.1. Summary of the Project

This project successfully developed a fully autonomous solar panel cleaning robot using an Arduino-based control system integrated with IR sensors, a rain detection module, and a water-assisted cleaning mechanism. The robot was designed to follow a bustrophedon (zigzag) cleaning path to ensure full panel coverage while avoiding edges using IR-based detection. The cleaning mechanism included rotating brushes and a water pump for more efficient dust removal, and the system was programmed to halt operations during rain for safety and water conservation.

Testing demonstrated reliable cleaning efficiency (over 90%), accurate edge detection, and consistent autonomous operation. The project proves that solar panel maintenance can be automated effectively using a low-cost, sensor-based robotic platform.

Table 6.2. Key Findings and Contributions

Contribution	Details
Autonomous Operation	Robot completed full cleaning cycles without human intervention.
Efficient Path Coverage	Bustrophedon path ensured near-complete panel surface coverage.
Reliable Edge Detection	IR sensors accurately stopped the robot before panel boundaries.
Rain Detection and Safety	Rain sensor halted operation within 2 seconds, protecting components.
Effective Cleaning	Achieved over 90% dust removal with brushes and water mechanism.
Low-Cost Design	Used cost-effective components while delivering robust functionality.

6.3. Limitations of the Current Implementation

6.3.1 Table of Current Limitations and Possible Solutions

Limitation	Impact	Possible Solution
Limited Cleaning Range	Cannot reach multiple rows or multiple panels	Add mobility or track system to shift across panels
Sensor Sensitivity Variation	Occasional false triggers from rain or light	Calibrate sensor thresholds; use shielding for accuracy
Water Usage Efficiency	Water may be wasted in low-dust conditions	Add dust sensors to activate pump only when needed
Manual Calibration Required	Needs tuning before first use	Automate calibration with startup sequence and presets
Limited Power Duration	Operates ~7 hours on a single charge	Integrate solar-powered battery charging system

6.4. Possible Improvements and Future Enhancements

1. Smart Dust Detection

- Integrate dust level sensors to activate cleaning only when necessary.
- Avoid unnecessary cleaning and conserve water.

2. AI-Powered Obstacle Recognition

- Use a Raspberry Pi with a camera module and basic ML model (e.g., YOLO).
- Allow robot to detect birds, debris, or unusual surface obstructions.

3. Solar Charging & Energy Optimization

- Embed solar panels on the robot for continuous daytime charging.
- Upgrade to low-power brushless motors and optimize motor driver efficiency.

4. Multi-Panel Coverage

- Implement a rail or mobility platform to cover multiple panels in one cycle.
- Ideal for large solar farms with rows of panels.

5. IoT Integration for Monitoring

- Use ESP32/ESP8266 for Wi-Fi connectivity.
- Enable real-time status updates and cleaning logs via a mobile app or dashboard.

6. Self-Diagnostics and Alerts

- Integrate error detection and LED/voice alert system for troubleshooting.
- Push critical faults or maintenance alerts to user via app.

Final Thoughts

The solar panel cleaning robot prototype successfully demonstrates that automated cleaning can be achieved using low-cost components, intelligent path planning, and basic sensor feedback. The robot consistently performed well under typical conditions and delivered measurable efficiency improvements in solar panel cleanliness. With additional development in mobility, AI, and connectivity, the system can scale for use in residential, commercial, and industrial solar arrays.

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