E L E C T R O N I C E N G I N E E R I N G P R O J E C T

Submitted in fulfillment of the partial

Requirement for the degree of Bachelor of

Engineering (Electronic Engineering)

Prototype Development of an Automatic and Flexible Solar Panel Cleaning Robot

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DECLARATION

I hereby certify that this dissertation constitutes my product, that where the language of others is set forth, quotation marks so indicate, and that appropriate credit is given where i have used the language, ideas, expressions, or writings of another. I declare that the dissertation describes original work that has not previously been presented for that award of any other degree of any institution.

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Date: 11-12-2023

DEDICATION

This report is dedicated to:

Our loving family, for their unwavering support

, encouragement, and sacrifices throughout this academic journey.

Our dedicated teachers and mentors,

whose guidance and knowledge have been invaluable in shaping this research.

Our friends, who provided moments of

respite and laughter, making the challenging times more bearable.

And to everyone who aspires to pursue

knowledge and create a better world through research and education.

This work is a testament to the collective

efforts of those who have touched my life.

QUAID-E-AWAM UNIVERSITY OF ENGINEERING SCIENCE AND TECHNOLOGY
NAWABSHAH

CERTIFICATE

This is to certify that the following students of the 19ES batch have completed the final year project in partial fulfillment of the requirement of a bachelor of engineering (Electronic) from Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah, Pakistan. The thesis titled **"Prototype Development of an Automatic and Flexible Solar Panel Cleaning Robot"** is submitted to the Quaid-e-Awam University of Engineering, Science and Technology, Nawabshah for the award of the degree of Bachelor of Engineering.

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We are also thankful to IGNITE National Technology of funds owned by the Government of Pakistan and administered by the Ministry of Information Technology and Telecommunication Pakistan for providing funds for this project.

PROJECT TITLE (Prototype Development of an Automatic & Flexible Solar Panel Cleaning Robot)

Sustainable Development Goals

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

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

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ABSTRACT

Pakistan has been facing an energy crisis for many years, and the performance of conventional electrical grids is insufficient. Renewable energy features are increasingly vital for emerging nations. The world is progressively shifting towards harnessing energy from sustainable sources. Among cutting-edge technologies such as photovoltaic (PV) cells, wind turbines, biomass plants, and fuel cell technology, photovoltaic technology emerges as a particularly promising solution with substantial room for improvement. It offers the advantage of generating energy without harming the environment. Solar power has emerged as a significant renewable energy source, and its applications should be expanded. Solar PV modules are frequently used in dusty environments, particularly in countries like Pakistan and India. Dust accumulates on the module's front surface, obstructing sunlight, and potentially reducing the module's power generation capacity. If not cleaned for a month, power output can decrease by as much as 50%. It is typically advised to frequently clean solar panels to preserve the efficacy and efficiency of the panels in order to solve this issue. There are several ways to keep solar panels clean, from manual washing to fully automated technologies**.**Traditionally, the cleaning of solar panels was a manual process. This approach had its downsides, such as the risk of staff accidents, potential damage to the panels, operational challenges, inadequate maintenance, and other issues. The adoption of automated dust cleaning systems for solar panels has effectively tackled these problems, providing a non-abrasive and efficient cleaning method while preventing productivity fluctuations caused by dust deposition.Most of the automatic and manual dust cleaning systems use water, like most of the robots clean solar panels with water, water can remove some of the grime that collects on panels over time, but it can also cause dirt to accumulate on the panels, and it is not sufficient to remove heavy pollution whereas the solar panel cleaning robot is a good alternative to keep solar panels clean. On the other hand, there is a big problem due to water scarcity in many countries. This project is the solution to all these problems. The prototype development of an automatic and flexible solar panel cleaning robot is aimed at enhancing the performance of photovoltaic systems. The robot employs autonomous navigation cleaning mechanisms, to efficiently clean solar panels across various terrains and environmental conditions. It has two degrees of freedom (horizontally and vertically). An automatic and flexible solar panel cleaning robot has a feature to operate with WIFI as well as manually. Through the firebase, the regular cleaning time of the robot can be set, and also robot can be operated anytime through WIFI. In case WIFI is not available, there is a manual feature, user can run the robot anytime by pressing the button. The robot will take

power as input from the same photovoltaic cell. This project is a good solution for maintaining the efficiency of solar panels for Pakistan as well as for other countries.

CHAPTER 01

1.1 Introduction

Pakistan is grappling with a severe energy deficiency, leading to daily power outages that affect consumers. Over recent years, there has been a substantial increase in energy demand, but the capacity to generate electricity has not grown in proportion. Projections indicate a three-fold increase in Pakistan's energy requirements by 2050, highlighting the substantial gap between demand and production. From 2013 to 2020, electricity demand grew at a rate of 7.8%, resulting in a demand of 27,840 MW in 2017 and 31,900 MW in 2020. In 2015, different electricity suppliers in Pakistan showcased their system capacities and power demands, as depicted in Figure 1. The Pakistan Electric Power Company (PEPCO) reported an average power deficit exceeding 5,000 MW, which continues to rise. The current electricity system faces significant operational inefficiencies, including theft and line losses, accounting for 19.7% of total electricity generated. Consequently, Pakistan experiences daily power failures that directly impact its economy [1].

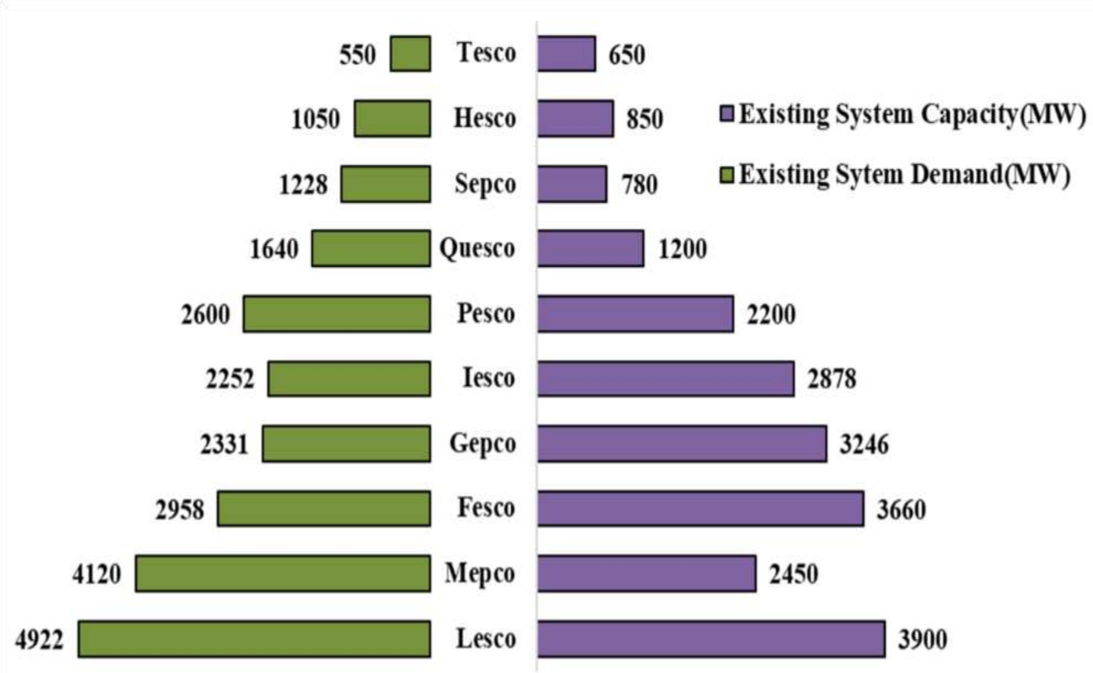

Figure 1: Comparison of system capacity and energy demand for different suppliers in Pakistan [1].

Energy is a fundamental requirement that impacts every aspect of human well-being. A country's economic development and its ability to sustain itself depend heavily on its access to electricity. In Pakistan, there's a significant demand for energy, both for industries and households, in order to advance the country's modernization. However, Pakistan faces challenges in ensuring a consistent supply of energy. The good thing is that Pakistan is rich in various energy resources. The key is to utilize these resources effectively to boost the country's economy. Figure 2 illustrates the energy resources available in Pakistan, which can be categorized into two main types: conventional and Renewable Energy Resources (RERs).Conventional resources include non-renewable energy sources, with thermal and nuclear energy being prime examples. Thermal energy is produced from fossil fuels such as coal and natural gas. On the other hand, RERs consist of energy sources that can naturally replenish, including geothermal, solar, wind, hydel (hydroelectric), waste heat, and biomass energies. Harnessing these resources efficiently is vital to ensure a sustainable and prosperous energy future for Pakistan [1].

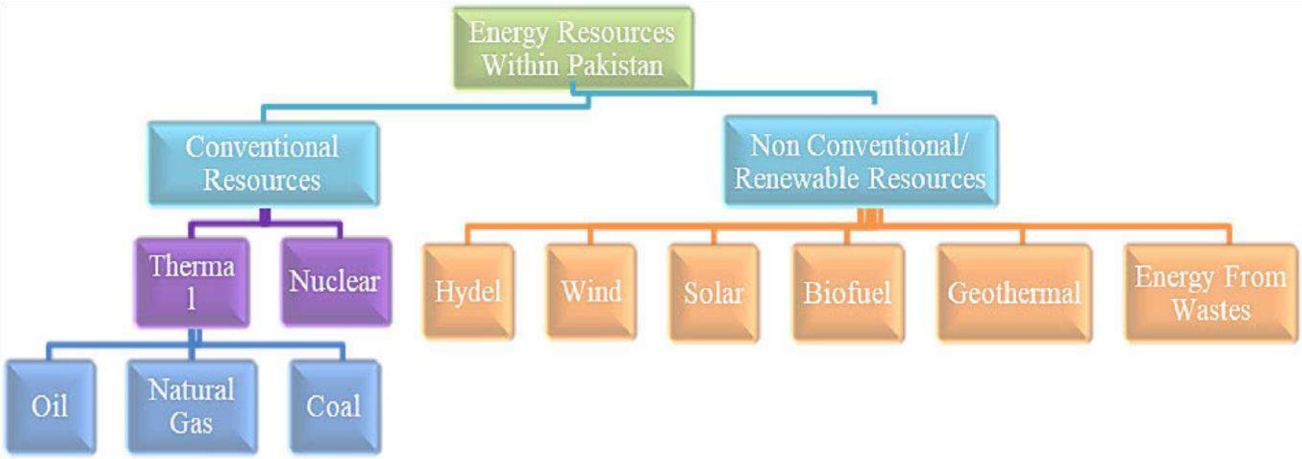

Figure 2: Energy resources within Pakistan [1].

Renewable energy attributes are gaining increasing importance in the context of developing countries. They encompass aspects such as the efficient utilization of resources, the climate-related consequences associated with pollutant emissions, and the conservation of non-renewable resources. As a result, the global trend is gradually shifting towards the production of energy from renewable sources. In this transition, modern technologies like photovoltaic (PV) cells, wind turbines, biomass facilities, and fuel cells are emerging as pivotal contributors to sustainable and widely accessible energy generation. Photovoltaic technology, in particular, stands out as a highly viable solution with considerable room for enhancement, offering clean energy production while minimizing its environmental footprint. This global move towards renewable energy sources is a significant step in addressing the world's energy and environmental challenges [1]. The sun radiates an abundant amount of energy, which, if fully harnessed, could easily meet the world's energy demands. However, this ideal scenario is hindered by atmospheric conditions like clouds, dust, and temperature fluctuations. Solar panels play a crucial role in converting solar energy into usable forms. There is an unprecedented interest in renewable energy, particularly solar power, as it offers a clean and carbon dioxide-free source of electricity. Among the various methods for harnessing solar energy, photovoltaic technology is considered a promising solution to meet the ever-growing energy needs. Nonetheless, the efficiency of solar panels is constrained by natural factors, making it essential to address parameters such as dust, humidity, and temperature to optimize the performance of solar energy systems [2]. One of the issues faced in the deployment of solar panels is the need for regular maintenance. A research study conducted at Quaid-e-Azam Solar Park in Bahawalpur examined the performance of PV modules during the summer months, specifically June, July, and August. The research indicated that the accumulation of dust on the surfaces of these modules led to a decrease in their efficiency.In more detail, the study quantified the density of dust accumulation on the PV module surfaces, which measured at 0.786 mg/cm^2 for June, 0.681 mg/cm^2 for July, and 0.601 mg/cm^2 for August at the end of the experiment. The study's results revealed a substantial reduction in the average power output, with a 22% decrease in June, a 16% decrease in July, and an 18% decrease in August due to dust accumulation. Furthermore, the efficiency of the polycrystalline PV modules experienced a noticeable decline, particularly in August when compared to June and July [3].

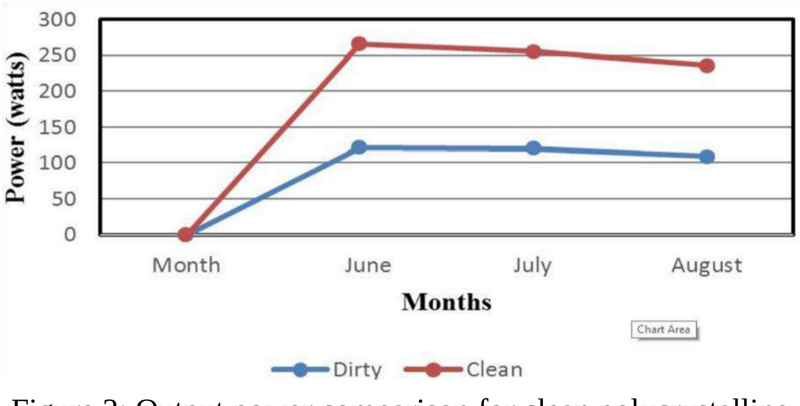

Figure 3: Output power comparison for clean polycrystalline PV module and dirty Polycrystalline PV [3].

In June, the power output of the PV module is substantially higher due to the abundant solar radiation typical of this summer month. However, even though these three months fall within the summer season with generally high power generation, the polycrystalline PV module's performance is adversely affected by the accumulation of dust. Dust settling on the module's surface leads to a voltage reduction when shadows are cast on the glass sheets of the PV modules.The study revealed that a clean, uncontaminated polycrystalline PV module exhibited superior power output compared to a polluted one, and it experienced a more significant percentage decrease in output power caused by dust buildup. As a result, there was an overall 3% reduction in the average power output of polycrystalline PV modules after three months of exposure to environmental conditions. This highlights the necessity of regular PV module cleaning to mitigate efficiency losses [3]. Following a year of exposure without cleaning, the systems were cleaned using pressurized distilled water spray with brushing. This cleaning process substantially improved energy generation efficiency, especially for one of the panels, which saw a notable 6.9% increase in efficiency. Maximum efficiency can be calculated according to equation (1).

$$\text{Maximum efficiency}= \frac{Max\ power\ output}{Incident\ radiation\ flux \times area\ of\ collector} \times 100 \qquad (1)$$

Numerous factors can impact the power efficiency of PV panels, including shadows, snow, high temperatures, pollen, bird droppings, sea salt, dust, and dirt. Dust, in particular, is a significant factor that can reduce a PV panel's efficiency by as much as 50%, depending on the environmental conditions. Cleaning these dirty panels with commercial detergents can be a laborious, expensive, potentially environmentally hazardous, and even corrosive process for the solar panel's frame.

Ideally, solar panels should undergo regular cleaning to maintain their peak efficiency, a task that becomes even more challenging for large ground-based solar arrays, which can consist of up to 22,000 panels covering a vast area of 20,000 square meters. Even the accumulation of dust on a single panel can noticeably impede energy generation efficiency. Therefore, it's essential to keep the panel surfaces as clean as possible.The current human-dependent methods of cleaning solar panels are resource-intensive in terms of time, water consumption, and energy usage. The absence of automation in solar panel cleaning highlights the urgent need for the development of automatic cleaning machines designed to efficiently and effectively traverse the glass surfaces of the panels. The efficiency of photovoltaic solar panels is gauged by their ability to convert sunlight into usable energy for human use [4].

A range of cleaning methods is utilized to uphold the efficiency of solar panels. In the past, manual cleaning was the typical approach, but it comes with several downsides. These drawbacks encompass staff safety risks, the potential for panel damage during cleaning, difficulties in maneuvering, and subpar maintenance practices [2].


Figure 4: Solar panel cleaning examples [7]- [8].

The practice of manual cleaning carries a considerable degree of risk, particularly when solar cells are situated at elevated positions, and the expense associated with cleaning each individual solar cell is notably high. With this in mind, the researcher sought to tackle the challenge of solar cell cleaning by designing a robot. The primary objective was to reduce the potential risks to human workers who would otherwise have to work at elevated locations during the cleaning process [5]. So, we aim to provide a non-wasteful approach to clean solar panels by using minimal amounts of power which is also taken from that solar panel ,while requiring little to no maintenance.The automatic and flexible solar panel cleaning robot excels in accessing challenging heights and offers extended operational capabilities. It moves across the solar panel surface using gear motors and employs brush for effective scrubbing during the cleaning process. This robot presents a compelling alternative within the solar cell industry, providing enhanced cleaning efficiency and flexibility.This system will not clean panels with the help of water because water is a valuable resource in arid regions such as the desert, etc.This system has two degrees of freedom, horizontally as well as vertically and, it will clean multiple solar panels regularly. An autonomous cleaning robot has the flexibility to cover distances from one panel to another panel, it also can cover the gap between the panels. The prototype development of an automatic and flexible solar panel cleaning robot can be controlled by firebase, its regular cleaning timing can be set through firebase, and also can be operated anytime through WIFI. In case WIFI is not available there is an extra manual feature by that, it also can be contrlloled, and operated.

1.2 Problem statement

The problem statement related to solar panels is that the accumulation of dust and debris on the surface of the solar panel reduces its efficiency and effectiveness in generating electricity which is problematic in decreasing power output. For maintaining their efficiency it should be cleaned regularly. There are many methods for cleaning solar panels.

Cleaning solar panels manually can be a challenging and time-consuming task, and there is also a human risk. Cleaning solar panels manually often requires workers to climb onto the roof or use ladders to access hard-to-reach areas, which can be dangerous and increase the risk of accidents or injuries. To address these problems, many solar panel owners are turning to automated cleaning solutions, such as solar panel cleaning robots, to improve the efficiency, safety, and effectiveness of solar panel maintenance but most of the robots clean solar panels with water. The water washes off the dust that collects on panels, however, the dust is reabsorbed on the panel due to the water. There is also a major issue in many countries the lack of water whereas some cleaning robotic systems have not focused on 2 degrees of freedom which is difficult to control from panel to panel when the panel is separated. To maintain the efficiency of solar panels, for maximum output an automatic and flexible solar panel cleaning system is required which can clean multiple and differently structured panels regularly.

1.3 Aim and objectives

1.3.1 Aim of the project

This project aims to develop a prototype of an automatic and flexible solar panel cleaning robot to maintain the efficiency of solar panels.

1.3.2 Objectives of project

- To design the prototype of a structure for solar panels.
- To develop a prototype of a solar panel carrier and cleaning robot.
- To test and verify the project.

1.4 Plan of work

The project requires in-depth research on the solar panel and the development of a cleaning robot. It also requires studying the interfacing of the motors through nodemcu.

Table 1: Plan of work

Task names/ Duration	Months									
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct
Literature review										
Writing proposal										
To design prototype structure of solar panels.										
Prototype development of cleaning robot										
Interfacing of motors										
Thesis writing										

1.5 Environmental and sustainability

An automatic and flexible solar panel cleaning robot is not harmful to the environment due to its eco-friendly cleaning solutions, no water usage, clean source of energy, gentle cleaning process, and reduced carbon emissions.

1.6 SDGS

This project is related to the following SDG which are mentioned below

1.6.1 Affordable and clean energy (7^{th})

This project can contribute to achieving this goal by improving the efficiency and productivity of solar panels by increasing energy output at lowering maintenance costs.

1.6.2 Industry, innovation, & infrastructure (9^{th})

This project can contribute to achieving this SDG goal by promoting the use of renewable energy and advancing technological innovation.

1.6.3 Sustainable cities and communities (11^{th})

An automatic and flexible solar panel cleaning robot can contribute to achieving the 11th SDG by promoting renewable energy, improving the efficiency of energy production, reducing energy costs, and promoting sustainable urban development.

1.7 Complex Engineering Problems (CEP) Attributes

This project is designed in a way to solve the complex engineering problem. The following characteristics of complex engineering problem are targeted in this project.

1.7.1 Depth of Knowledge Required (WP1)

In the development of an automatic and flexible solar panel cleaning robot requires a depth engineering knowledge. A deep research based understanding of environmental factors, and specific needs of solar panel maintenance.

1.7.2 Range of Conflicting Requirements (WP2)

Designing an automatic and flexible solar panel cleaning robot presents a range of conflicting requirements. Striking a delicate balance between factors such as lightweight for mobility, precision, and speed, and autonomy and adaptability.

1.7.3 Depth of Analysis Required (WP3)

Developing this project necessitates a thorough depth of analysis. This encompasses a detailed examination of various critical aspects.

1.7.4 Familiarity of Issues (WP4)

Familiarity with the specific issues related to automatic and flexible solar panel cleaning is essential for the design and implementation of effective solutions. Understanding the unique challenges of weather conditions, and panel materials is crucial for developing cleaning systems that can adapt to different environments.

1.8 Complex Engineering Activities (CEAs)

The following CEAs are mentioned which are related to this project.

1.8.1 Range of Resources (EA1)

Automatic and flexible solar panel cleaning robot utilize advanced equipments, materials, and technologies to ensure efficient cleaning.

1.8.2 Level of Interactions (EA2)

In this project the level of interactions between cleaning robots and the panels themselves involve precise navigation and cleaning mechanisms that adapt to the specific layout and contours of the panels.

1.8.3 Innovation (EA3)

In this project, the innovation involves the application of new technologies and methods to enhance the efficiency and effectiveness of the cleaning process.

1.8.4 Familiarity (EA5)

Familiarity is harnessed in automatic and flexible solar panel cleaning robot through advanced algorithms that allow them to update about the efficiency of the panel and daily cleaning notifications.

1.9 Organization of thesis

Chapter 2 provides the literature review is explained by combining all the researcher's work and projects designed with different controllers. This research contains detailed knowledge about solar panels and their cleaning methods.

Chapter 3 provides information about the hardware and software installations which includes components used in this project and discusses the methodology of an automatic and flexible solar panel cleaning robot.

Chapter 4 provides information about the experiments performed for the evaluation of the proposed model and gives the results achieved from the experiments.

Chapter 5 describes the conclusion and future enhancement of the system.

1.10 Funding

This project receives its funding from IGNITE National Technology Fund, a government-owned fund administered by the Ministry of Information Technology and Telecommunication in Pakistan.

CHAPTER 02

2.1 Literature review

In recent years, several studies have been conducted to design and develop solar panel cleaning robots with different cleaning mechanisms and control systems. These studies aim to optimize the robot's navigation and cleaning abilities to improve their efficiency and accuracy in cleaning solar panels. The researchers have been exploring the possibility of developing solar panel cleaning robots for many years. The following literature review summarizes the research that has been conducted on the topic.

In this study research paper, due to the buildup of dust on the surface of photovoltaic modules, the performance of photovoltaic modules of polycrystalline technologies was carefully examined. For three consecutive months throughout the summer, the photovoltaic modules used in this study were subjected to the outside working conditions of the Quaid-e-Azam solar park in Bahawalpur. The buildup of dust that was deposited on solar modules' surfaces reduced their efficiency. The average output power increased to 22% for June, 16% for July, and 18% for August, according to the researcher's analysis, which was caused by dust gathering on the solar modules' surface. The buildup of dust also caused a noticeable decline in the efficiency of the modules. In comparison to June and July, the percentage of photovoltaic modules' efficiency that decreased in August was larger. Regular solar module cleaning is essential to prevent efficiency loss [3].

According to the researcher, the effectiveness and performance of the solar panels were found to be significantly impacted by dust. Peak power generation may be reduced by up to 10% to 30%. Power loss was noticed as a result of dust buildup on the panels, and robotic cleaning techniques can help. The solar panels' ability to generate electricity has grown. The design and development of a robot that could automatically clean solar panels were discussed in the study. A PIC microcontroller, a power source, a carrier mechanism, and a cleaning mechanism were all included with the robot. The carrier mechanism is composed of a DC motor and sensor, which facilitates switching from one panel to another. The cleaning mechanism was composed of a rotatory brush to assist in cleaning the solar modules' surface. Without human assistance, the robot was able to clean the panels, resulting in lower labor costs, more efficiency, simpler maintenance, and less power consumption [4].

This paper discusses the use of solar PV modules in dusty environments, which is a common occurrence in tropical countries like India. In such conditions, the power output of these modules can decrease by as much as 50% if they are not cleaned for a month. To address this issue, a cleaning system has been developed that controls the cleaning process using Arduino programming to remove dust from the PV modules and enhance their power efficiency. Traditional cleaning of solar panels was a manual process, but it had its drawbacks, including safety risks to staff, potential panel damage, mobility issues, and inadequate maintenance. The automated dust cleaning system for solar panels aims to overcome these challenges and prevent fluctuations in productivity due to dust buildup. Studies were conducted to assess the efficiency of dusty solar panels compared to cleaned ones. The results clearly showed a significant increase in solar panel efficiency after cleaning. The solar panel cleaning system consists of a brush operated by DC motors, and the brush's movements are controlled by signals generated through Arduino. The frame carrying the cleaning brush moves vertically over an 11ft distance and shifts horizontally over a 9ft distance to clean three sets of solar panel arrays. The entire cleaning process takes 300 seconds and is subsequently repeated. This regular cleaning action helps prevent the accumulation of stubborn dust on the solar panels.In conclusion, the solar panel cleaning system effectively removes dirt and debris from PV modules, resulting in improved efficiency and enhanced energy output [2].

Solar cell efficiency typically experiences an annual decline of 3-6%, and this issue is particularly prominent in regions with high dust levels, such as Middle Eastern countries. Thailand faces a unique challenge, with both dust and stains contributing to a substantial 35% reduction in solar cell efficiency. While manual cleaning of solar cells is a common practice, it comes with inherent risks, especially in cases where solar cells are installed at elevated locations. Additionally, the cost of cleaning each solar cell is prohibitively high.In response to these challenges, the researcher set out to design and develop a solar panel cleaning robot tailored to Thailand's needs. This robot is equipped with a wireless joystick, sonar sensors, gear motors, and an Arduino microcontroller to facilitate its operation. It utilizes a rotary brush and water spray to enhance the cleaning process.The solar panel cleaning robot, driven by gear motors, can operate effectively within a temperature range of 0-30 degrees Celsius. The cleaning system, employing a rotary brush, can proficiently clean 80% of the solar panel's surface. The robot also features an ultrasonic sensor, a battery, and a solar brush for cleaning. It covers an area of approximately 54 square feet in just 30 seconds and commences its operations at sunset to avoid casting shadows that might affect electricity generation.This innovative approach not only eliminates human risks associated with cleaning but also significantly improves solar panel efficiency [5].

CHAPTER 03

3.1 Research methodology

The proposed solar panel cleaning robot is designed to eliminate dirt and dust that accumulate on solar panels, thus optimizing their energy absorption capacity. The system is composed of two main parts: the cleaning robot and the carrier robot. The carrier robot serves as a transporter, facilitating the movement of the cleaning robot from one panel to the next.The carrier robot is a complete structure of mild steel rods which looks like a rectangular frame of four rods. A carrier robot has eight wheels, four wheels are supporting wheels and four wheels are for the movement of the carrier robot. Wheels move with the help of two dc gear motors and these two motors are only attached to two backward wheels, carrier robot moves horizontally on the surface of two separate rods which are attached to the top and bottom structure of solar panels. The cleaning robot travels on that carrier robot structure and covers the entire length of the panel with the help of eight wheels. Cleaning robot moves up and down with the help of a pulley and belt. When the pulley motor rotates in a forward direction belt becomes free, due to the smoothness of rods and elevated structure of panels cleaning robot goes down easily, the same way the motor rotates in a backward direction it comes backs to its initial position with the help of belt because belt takes the cleaning robot upward with itself. When the cleaning robot moves up and down a brush which runs with the help of a DC motor is also attached to the cleaning robot which clean the dirt and dust from the panel. Four limit switches are attached to the robot, two on the top and bottom of the carrier robot for guiding the carrier robot that it has reached the end and initial position, and the other two are attached to the starting position and end position of the structure of the solar panel to assist the carrier robot that it has been reached to an initial position, and also one proximity sensor is attached to the carrier robot which detects each plate position by detecting the metallic rod with the help of it carrier robot will understand that it is upon the accurate place of the solar panel now it has stopped as the cleaning robot can clean it, and metallic rod is attached to the end of every solar panel with the frame of solar. The robot is programmed to an ESP32 which controls its operations and its movement from one panel to the other panel. The main purpose of this system is to clean multiple solar panels using a single robot.

3.2 Working principle

The carrier robot moves towards the solar panel with the cleaning robot when the inductive proximity sensor detects the metal rod instead of stopping it, receiving the signal from the ESP32 the cleaning robot moves the entire length of the solar panel both forward and backward direction two limit switches are attached for help instructions. When it reaches the end of the limit switch the solar panel sends a signal that it has reached its end point and, it returns to its starting position where another limit sends a signal to the controller that the cleaning robot has reached its initial position and the system is ready to move to another panel. The carrier robot moves to the next panel and the rest of the process continues. The controller sends signals to the cleaning robot to perform the cleaning process. The movement of the carrier robot is controlled by the driver BTS7960 H bridge, the pulley motor is also controlled by other BTS7960 modules and the operation of the brush motor is controlled by the 1-channel relay module as it no need for counterclockwise or speed variation. After cleaning the panel, the cleaning robot reaches the starting position and transmits the signal to the carrier robot. As soon as the carrier robot receives the signal, the carrier robot moves to the next panel along with the cleaning robot. When the carrier robot stops its movement, the cleaning robot travels the entire length of the panel in the forward direction after receiving a signal from the carrier robot. Moving forward, the cleaning robot removes dust and dirt accumulated in the panel with a brush attached to it. After the panel reaches the end point, it travels in the reverse direction and reaches the starting position. Now the carrier robot again transmits the signal to the carrier robot. After receiving the signal the carrier robot starts moving towards the new panel and stops when the proximity sensor detects the metal rod and the process continues. After clearing all the panels it will shut down and resume its operation after 24 hours or at the user's time or any time the user wants to clean the panels through Firebase and Wi-Fi connection, and if Wi--Fi is not availble solar panels can also be cleaned at any time through a manual switch.

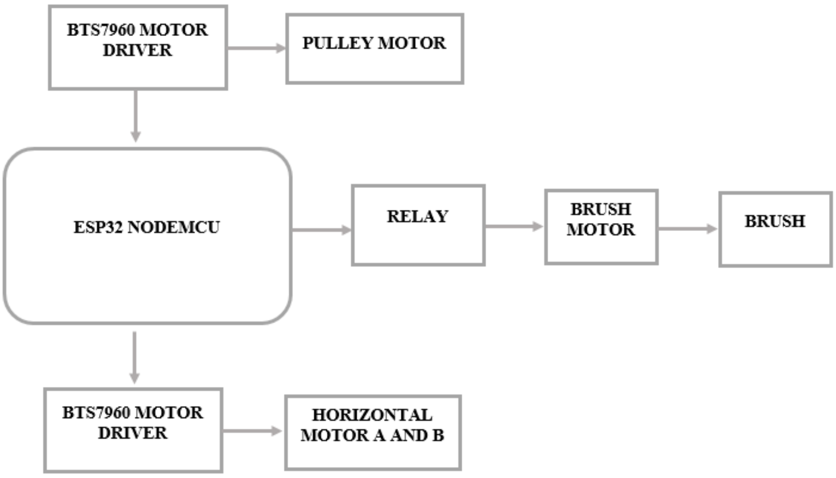

Figure 6: Block diagram of project.

Figure 6 is the block diagram of the solar panel cleaning robot in which the main controller is ESP32 and different motors help the robot move and clean the solar panels.

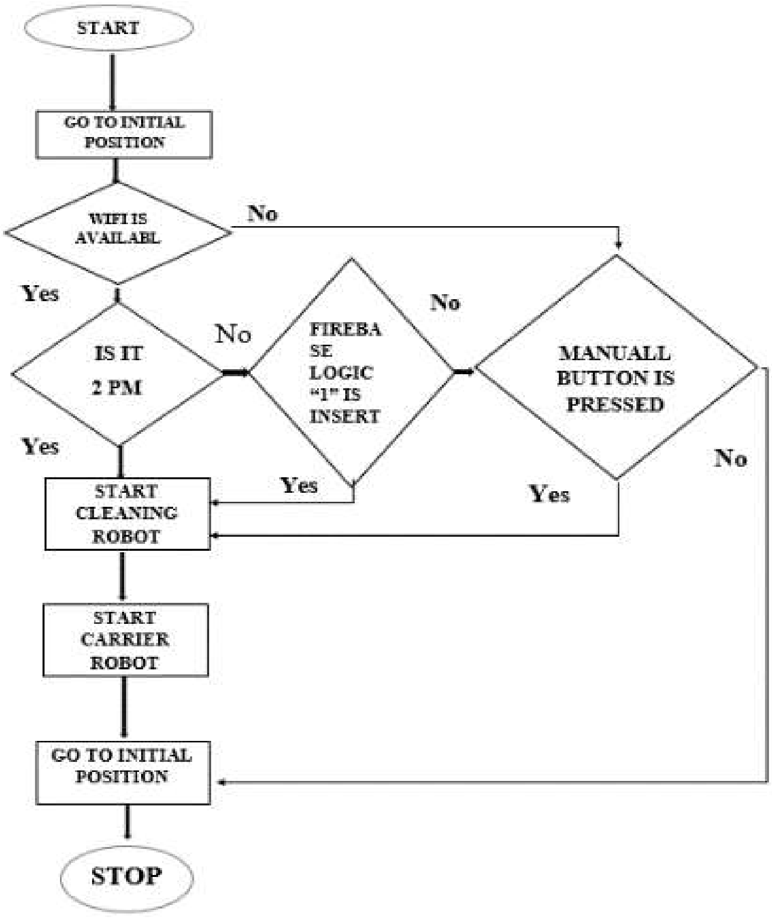

Figure 5: Project methodology flow chart.

Figure 5 shows the complete process and logic condition of the robot for cleaning operation. When it starts it will check the initial position of the cleaning and carrier robot and set them to their initial position after that it will find the WIFI connection if it is available it will download the data from the fire database and check the cleaning time if given time match to the current time it will start cleaning operation if it does not match it will be another condition that user has given any command to robot through fire database to clean the panels right now if yes it will start cleaning if not it will see last condition that manual button/switch is pressed if yes it will start cleaning operation if not it will stop and wait for the cleaning time if WIFI is connected if it is not connected it will try to connect with it.

3.3 Implementation of project

The project consists of hardware and software co-design which are given below.

3.3.1 Hardware components

These are the components that are used in hardware design.

3.3.1.1 ESP32 NODEMCU

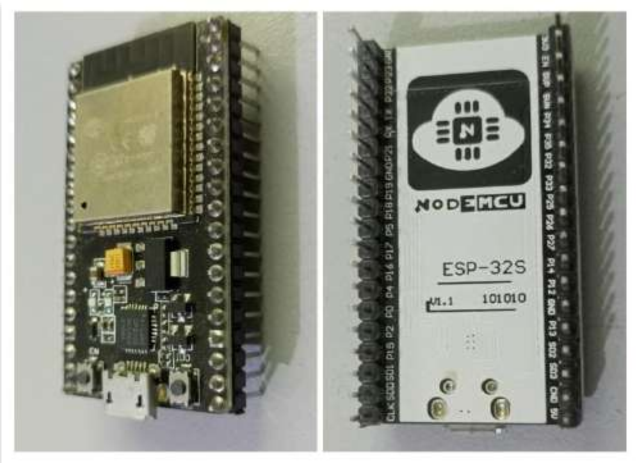

Figure 7: ESP32 [@ control lab].

The ESP32 DevKit V1 features a comprehensive pin configuration, totaling 30 pins. These include 25 General-Purpose Input/Output (GPIO) pins, two Analog to Digital Converters (ADCs), two Digital to Analog Converters (DACs), three Serial Peripheral Interface (SPI) pins, one Inter-Integrated Circuit interface (I2C), and two power pins.In this project 18, 19, 22, 21, 27, 26, 25, 27, and 33 GPIO pins have been used for BTS7960 module output controls, to control the DC gear motor direction and speed, the 14th pin is for the relay module,which controls to trigger the brush motor, the 23rd GPIO pin is used for the push button, the 32nd GPIO pin is used for inductive proximity sensor input, and 34,35,36,39 GPIO pins are used for input of limit switches.

3.3.1.2 Gear motor

Figure 8: Gear motor [9].

This type of DC gear motor is mostly used in car windows, due to its specification it is used in this project. It has only two pins +ve, and –ve. The purpose of this motor is to control the movement and direction of the robot. Operating at a voltage of 12VDC, this system exhibits a speed range between 51 and 100 RPM, with a torque range of 20.01 to 30.00 kg. cm. The current draw is below 15A.

3.3.1.3 DC motor

Figure 9: DC motor [9].

12V Dc motor is used for the rotation of brush of the cleaning robot. When the cleaning robot reaches solar panel, the Dc motor will turn on and rotate the brush.

3.3.1.4 BTS7960 motor driver

Figure 10: BTS7960 motor driver [11].

The BTS7960 module serves as a robust high-current full-bridge motor driver, specifically designed for the control of DC motors. It accommodates input voltages within the range of 6V to 27V and possesses the capability to handle a maximum current load of 43A. These modules utilize the Pulse Width Modulation (PWM) technique for DC motor control. This involves converting a consistent input voltage into a variable voltage output for the motor, enabling the regulation of motor speed.In PWM operation, the module maintains a fixed frequency while controlling the motor's speed by adjusting the duty cycle, thereby determining when the pulse is in the HIGH state. Below are the pin functions of the BTS7960 module:

- **VCC:** Power supply for the module - 5V
- **GND**: Ground
- **IS-R**: Input signal for detecting high current - for straight rotation
- **IS-L:** Input signal for detecting high current - for inverse rotation
- **EN-R:** Output signal for controlling motor direction - for straight rotation
- **EN-L:** Output signal for controlling motor direction - for inverse rotation
- **WM-R**: PWM signal for controlling motor speed - for straight rotation
- **PWM-L:** PWM signal for controlling motor speed - for inverse rotation

High current motor pins

- **M+:** Motor Positive
- **M-:** Motor Negative
- **B+:** Battery Positive
- **B-:** Battery Negative

In this project, PWM-R, and PWM-L pins of BTS7960 have been used for controlling the forward and backward speed of motors and EN-R, and EN-L pins have been used to control the direction of motors, and the other common pins are used such as, 5V VCC, ground and external supply pins for input and output.

3.3.1.5 LM2596-Buck converter

Figure 11: Buck converter [@control lab].

The LM2596 power supply module is a step-down (buck) DC-DC converter designed to regulate voltage. It can efficiently handle loads of up to 3A while ensuring consistent regulation even when dealing with changes in input and output conditions. This module is available in different variants, offering fixed output voltages like 3.3V, 5V, and 12V, and it also includes an adjustable output version for flexibility. Notably, the LM2596 series operates at a switching frequency of 150 kHz, making it a versatile and adaptable choice for various applications.In this project, it has been used to convert 12V DC to 5V DC to give input source to the desired components such as relay module, BTS7960, esp32nodemcu controller, proximity sensor, and limit switches. The operating voltage of the system is 12V DC, so a converter is required for those components which can only operate at 5V to converts the input from 12V to 3.3V for providing a power source. Specification of buck convertor are given below.

- Acceptable input voltage: 3-40V
- Adjustable output voltage range: 1.5-35V
- The module is rated for a constant output current of 2A, with a maximum of 3A achievable when additional heat dissipation measures are employed.
- Module Type: Non-isolated constant voltage module
- Rectification Method: Non-synchronous rectification

- Features short circuit protection with automatic recovery.

3.3.1.6 Parachute fabric brush

Figure 12: Parachute fabric brush [From project].

In this project parachute fabric is used as a brush, it is attached to the cleaning robot along a single steel rod, which rotates with the help of a DC motor and performs the cleaning operation. The parachute fabric brush is rotated in a fixed area of the cleaning robot. The length of the brush is 12 inches and the width is 13.5 inches. . It can be replaced or changed easily there are three nuts and bolts are used to hold it, they can be easily open by a commonly used screw driver.A user can change it or wash it if needed ,mostly it do not required cleaning because it is parachute fabric, it does not absorb dust or water.

3.3.1.7 1- Channel relay module

Figure 13: 1-channel relay module
[@control lab].

The relay module is a single-channel 12V relay interface board with a screw terminal, designed for direct control by a wide range of microcontrollers. It incorporates a high-quality relay that can manage up to 15A at 125V or 10A at 250V AC. The relay provides three essential connections: Common (COM), Normally Open (NO), and Normally Closed (NC).In this project relay module has been used to control the power on and off of the brush motor.

3.3.1.8 PC817C optocoupler

Figure 14: PC817C optocoupler [10].

It is used between the proximity sensor and ESP32 to provide isolation and get 6V input logic current from the proximity sensor and provide 3V input logic current to ESP32. Main features of PC817 are given below.

- Current transfer ratio (CTR: MIN 50% at IF=5mA, VCE=5V)
- High isolation voltage: 5000V effective value
- Compact dual-in-line package

3.3.1.9 Limit switch

Figure 15: Limit Switch [@ control lab]

In this project four limit switches has been used to inform controller about the initial and end position of carrier and cleaning robot.

3.3.1.10 Inductive proximity sensor

Figure 16: Inductive proximity sensor [@ control lab]

The inductive proximity sensor is used to detect the metallic material. In this project metallic rods are attached to the robot at the end point of the solar panels. When the carrier robot covers the whole panel the metallic rod is detected by the proximity sensor and proximity sensor, which gives a signal to the controller, that carrier robot has been reached over the solar panel and now the cleaning robot has to clean the solar panel. For multiple solar panels multiple rods are attached.

3.3.1.11 Solar panel

Figure 17Solar Panel and its Specification

The 10W solar panel is made up of high-quality silicon cells and other materials. This panel weight is 1 kg. Its size is 35x25 cm. In this project, it has been used for checking the efficiency of solar panels before and after the cleaning from the robot.

3.3.1.12 Power supply

Figure 18: DC Power supply [@ control lab].

The power supply (12V, 10A) is used to provide a power to the electronic circuit. It is used in this prototype because the 10W solar panel has been used, which is too small. It cannot be provide the required power to the project. While the time of implementation there is no need of external power supply, the robot can be operated from installed solar panel. The minimum power of that solar panel should be 12V and 10A.

3.3.2 Software component

3.3.2.1 Arduino IDE

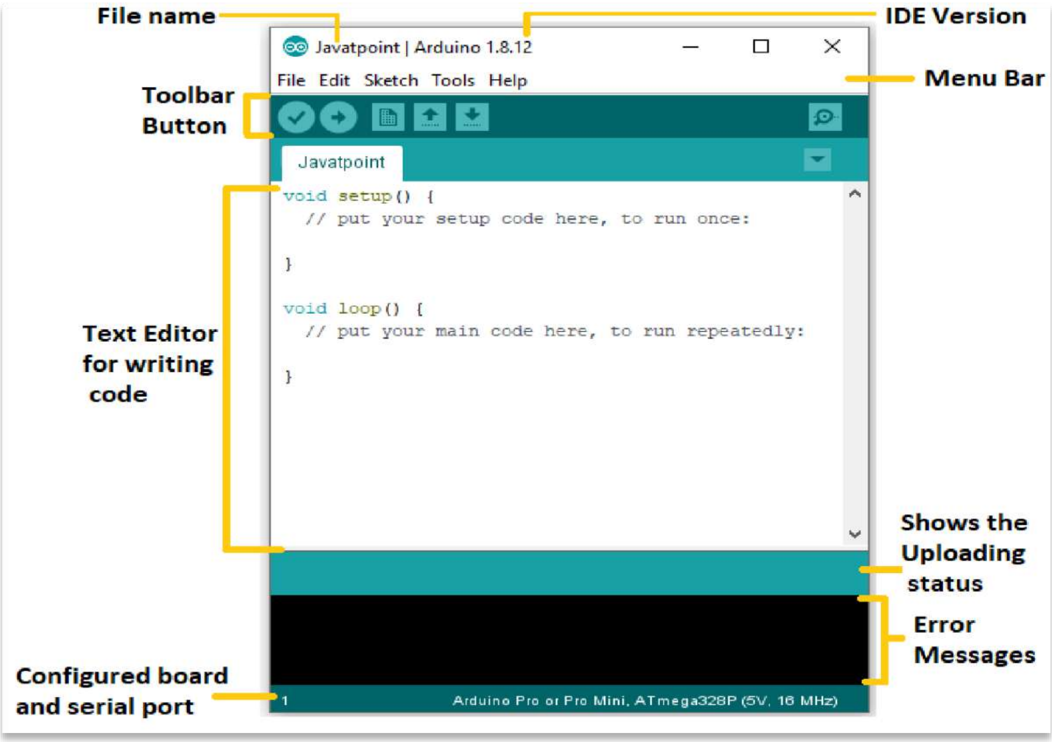

Figure 19: Arduino IDE software [6]

The Arduino Integrated Development Environment, also known as the Arduino Software (IDE), consists of several essential elements: a text editor for code writing, a message area, a text console, a toolbar with common function buttons, and various menus. This IDE establishes a connection with Arduino hardware for uploading programs and communication. Programs written within the Arduino Software (IDE) are termed "sketches." These sketches are created in the text editor and are saved with the .ino file extension. The editor offers features like cut, paste, search, and text replacement. The message area provides feedback during actions like saving, exporting, and error displays. The console section presents text output generated by the Arduino Software (IDE), including complete error messages and additional information. In the bottom right corner of the window, you can view the configured board and serial port. The toolbar buttons enable operations such as program verification, uploading, sketch creation, opening, saving, and access to the serial monitor. Using this software, the code of the project is written and uploaded into the ESP32, and also added libraries of ESP32 board and firebase. For adding the board of ESP32 in the tool setting menu there is an option of board manager through which NodeMCU board can be installed.

3.3.2.2 Firebase

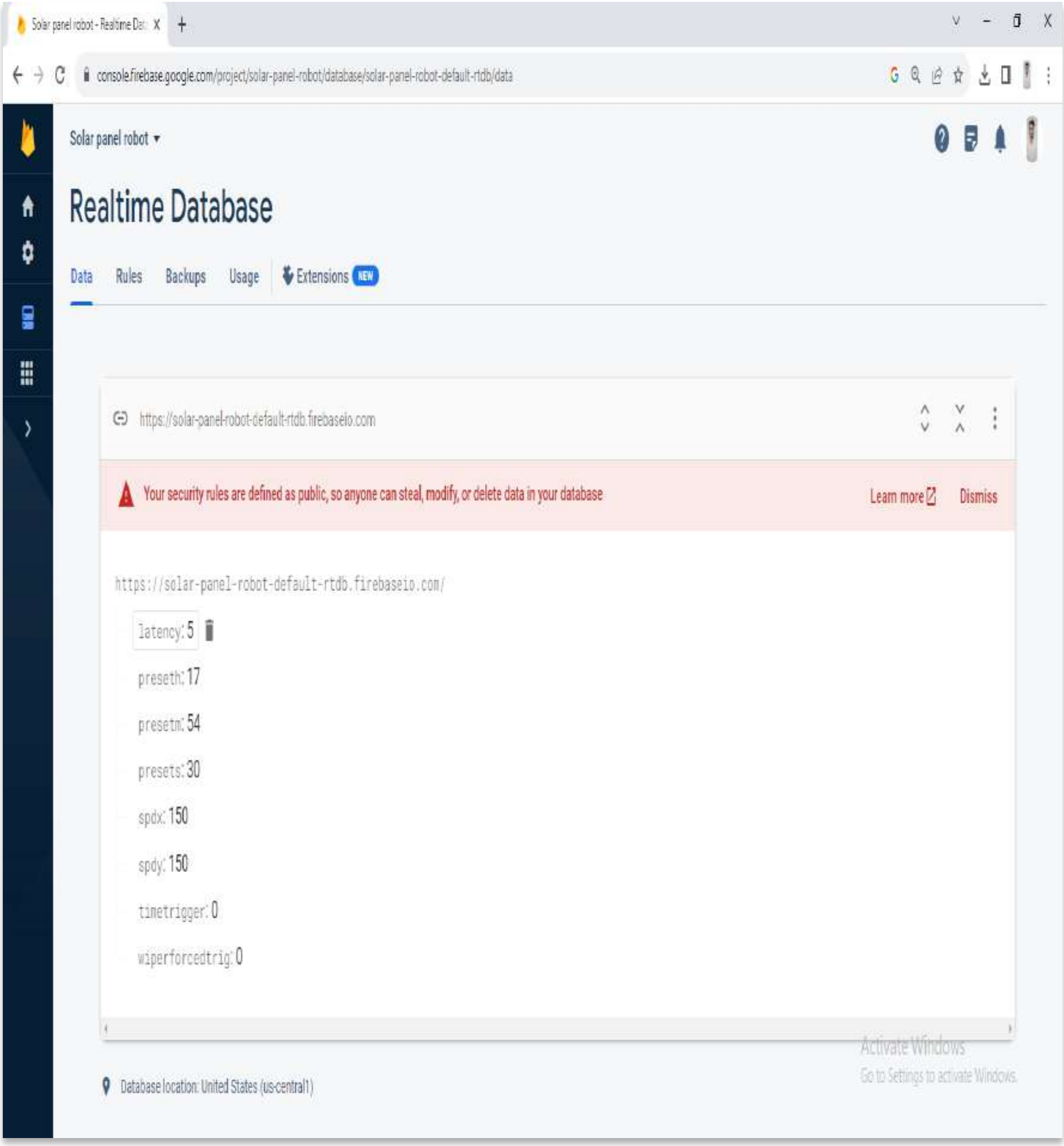

Figure 20: Firebase real-time input screen [From firebase acount].

Firebase is an application development platform that helps to build and grow applications and games users. The Firebase real-time database is a cloud-hosted NoSQL database that store and sync data between your users in real life. In this project, the Fire database has been used to give real-time data through the Firebase platform. Firstly, open a Google Chrome type Firebase, log in or sign in with your Gmail ID, go to the console, set your project name, select the real-time base option, and set a variable of the projec.As shown in Figure 20, latency variable is shown, the tolerance of time assigned as ±5. For example if you have set time at 2:15 it can either run the system at 2:10 or 2:20. Preseth is the variable for hours, presetm is for minutes and presets is for seconds, while spdx and spdy are the speeds of motors. Time trigger is the preset run time of the robot and wiperforcedtrig is the instant operating option to operate the robot. These all are the variables.

3.3.3 Hardware and software co-design

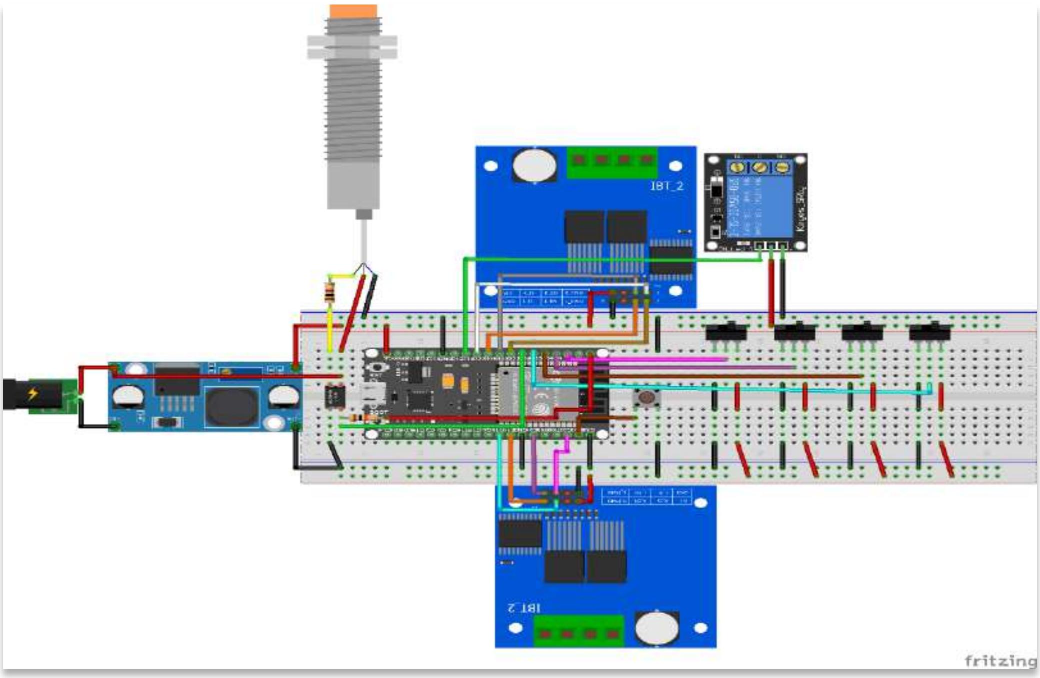

Figure 21: Circuit diagram of the project.

Four motors are used to run the robot, two of which are for the forward and backward movement of carrier robot. Carrier robot is controlled by the ESP32 controller and BTS7960 motor driver, while only one BTS7960 motor driver controls these two motors, and two limit switches are attached with the initial and end point of the solar panel's structure which gives signal to the controller that the robot has reached its initial, and endpoint. After receiving this information, the controller gives a signal to BTS7960 to control the direction of the motor.

Third motor is used for the upward and downward movement of the cleaning robot which moves up down, with the help of a pulley and belt drive, connected with the motor. This motor is also controlled with another BTS7960 motor driver which control the forward and reverse movement of the robot, while BTS7960 is controlled by the main controller ESP32, and the other two limit switches are attached to the structure of the robot at the starting and end point, which helps the controller to understand the initial and final position of the cleaning robot. The last motor is the brush motor which is attached to parachute fabric and works as a brush. This motor operation is controlled by the 1-channel relay module which is also primarily controlled by an ESP32 controller, the controller only switches on and switches off the motor with the help of relay. When cleaning robot starts from initial position, brush also starts revolving and when it again reaches the initial position, controller stops the motors that powers the brush and pulley. The inductive proximity sensor is attached to the bottom of the carrier robot which detects the rods which are attached on the end point of every panel. Proximity tells the controller that the carrier robot has reached the panel and after cleaning that panel, the same way proximity detects every rod and tells the controller that the carrier robot has been reached on another panel. Buck convertor provides 5V DC power to all desired components and optocoupler is used for isolation.

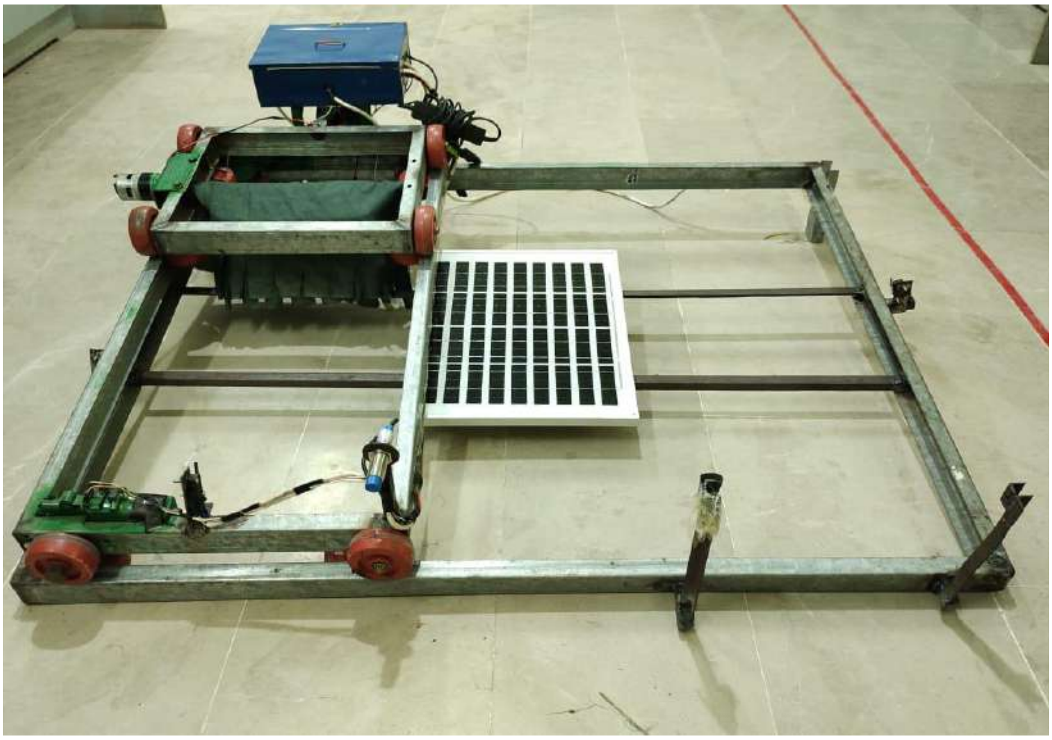

Figure 22: Complete prototype of project.

Figure 22 shows complete hardware and software combination of the project. The structure of the robot and solar panel is shown clearly in the figure. On the top of the robot a circuit box is attchaed, which is a complete electronic circuit of the project is in that box, which is shown seprately in Figure 23.

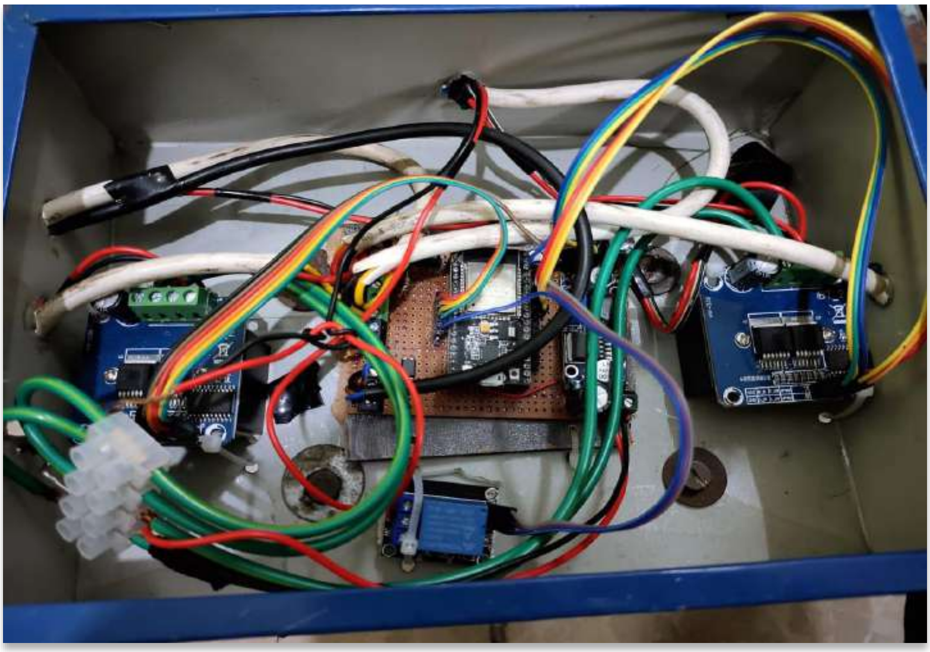

Figure 23: Electronic circuit of the project [From project]

Figure 23 shows the complete electronic circuit of the solar panel cleaning robot.

CHAPTER 04

4.1 Results and Discussion

The experiments performed for the evaluation of the proposed model and the results achieved from the experiments are discussed briefly here.

4.1.1 Cleaned solar panel measured results

Figure 24: Clean solar panel

The voltage, current, and power of the clean solar panel has been measured at a warm and sunny weather, the measurement shows results, which are given below in Table 2.

Table 2: Cleaned solar panel measured results

Voltage	22.14V
Current	0.454A
Power	10W

4.1.2 After dirt and dust solar panel measured results

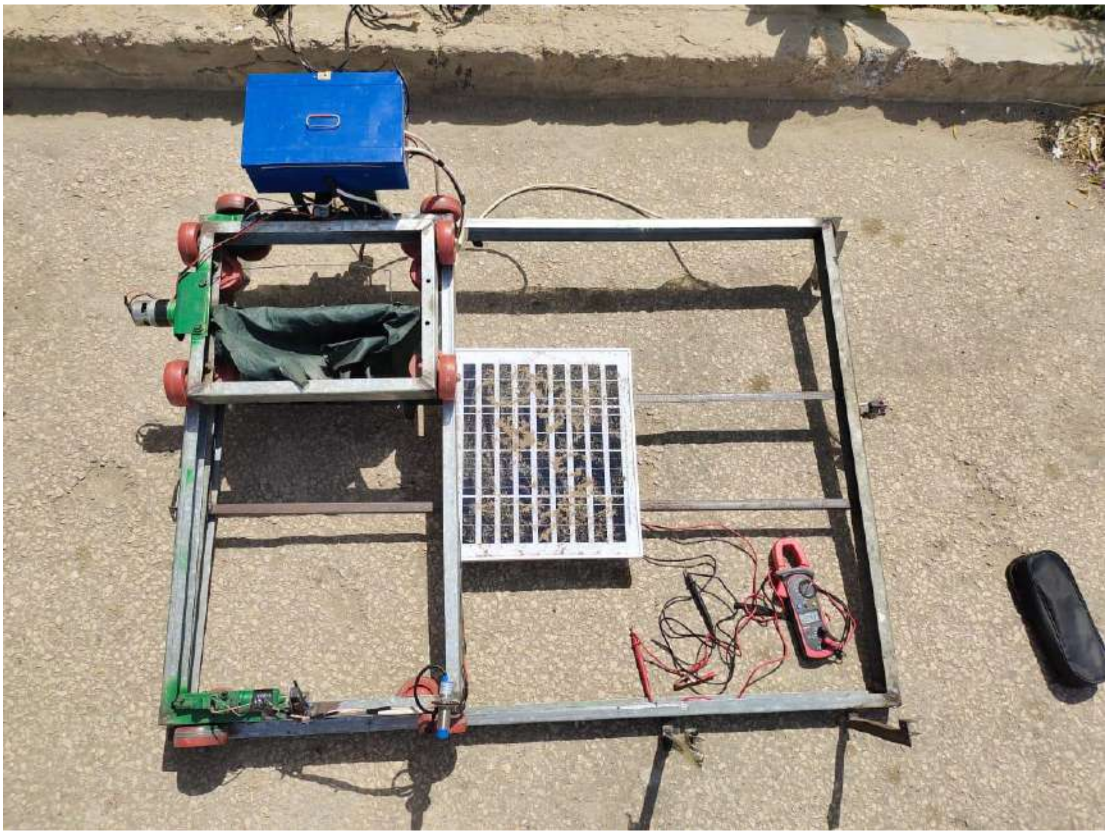

Figure 25: Dirty solar panel.

After the dirt and dust on the solar panel, the measurements showed the voltages, current and the power of the solar panel is decreased.

Table 3: Dirty solar panel measured results

Voltage	21.3V
Current	0.159A
Power	3.38W

Table 3 shows measured results,dirty solar panel voltage was measured 21.3V ,while the before dirt and dust solar panel measured voltage was 22.14V as shown above in Table 2 The current of dirty solar panel was also measured which is 0.159A and before dirt and dust solar panel current was 0.454A. The power of dirty solar panel was calculated after the measurement of voltage and current ,which is 3.38W, while before dirt and dust solar panel power was 10W.

These calculations shows volatage, current, and power claculations of solar panel before dirt and dust, and after the dirt and dust. Aaccording to overall measurements power of solar panel is decreased from 10W to 3.38W .After these measurements and calculations, the solar panel was cleaned with a solar panel cleaning robot, after the cleaning again voltage, current ,and power was measured and calculated which is shown below in Table 4.

4.1.3 Solar panel measured results after cleaning with robot.

Figure 26: Solar panel's voltage after cleaning.

As shown in Figure 26, after cleaning with a solar panel cleaning robot the voltage of the solar panel has been increased. The increased solar panel's power is almost double as compared to the dirty solar panel.

Table 4: After cleaning with robot solar panel measured results

Voltage	21.8V
Current	0.317A
Power	6.93W

4.1.4 Solar panel efficiency

Different measurements of voltage, current, and power of the solar panel were measured, before and after the cleaning with the robot which is mentioned below.

Table 5: Solar panel efficiency

S: No	Voltage **Before** cleaning	Voltage **After** cleaning	Current **Before** cleaning	Current **After** cleaning	Power **Before** cleaning	Power **After** cleaning	Efficiency **Before** cleaning	Efficiency **After** cleaning
1	21.3V	21.8V	0.159A	0.3179A	3.38W	6.93W	33.8%	69.3%
2	21.3V	21.7V	0.165A	0.3369A	3.514W	7.3W	35.14%	73%
3	21.4V	22V	0.22A	0.3292A	4.7W	7.24W	47%	72.4%
4	21.6V	22.02V	0.3095A	0.38857A	6.6W	8.56W	66%	85.6%

4.1.5 Power consumption of prototype

The Power consumption of project is 73.2W(current=6.1A and voltage=12V).

Table 6: Power consumption of motors

Name	Current	Voltage	Power
Horizontal motor A	2.8A	12V	33.6W
Horizontal motor B	2.3A	12V	27.6W
Brush motor	2.6A	12V	31.2W
Total power consumption	6.1A	12V	73.2W

CHAPTER 05

5.1 Conclusion

In conclusion, the development and implementation of a solar panel cleaning robot offer significant advantages in enhancing the efficiency and productivity of solar energy systems. By automating the cleaning process, this innovative technology minimizes downtime, reduces manual labor costs, and ensures optimal energy output from solar panels. Through careful mechanical design and software development, the robot can effectively navigate various panel configurations and avoid obstacles, all while executing precise and efficient cleaning patterns. Moreover, the incorporation of safety features ensures that the robot operates safely and reliably in diverse environments. The continued evolution of solar panel cleaning robots holds the promise of further advancements in renewable energy technologies, fostering sustainable practices and contributing to a cleaner and greener future. As research and technology progress, solar panel cleaning robots are poised to become an indispensable tool in the maintenance and widespread adoption of solar energy, driving us closer to a more environmentally conscious and energy-efficient world.

5.2 Future work

A separate application can be developed to operate the robot instead of Firebase. In this project fire base website has been used to set the cleaning time of the robot and operate, it on users requirement, an advanced application can be developed to set the cleaning time of robot and many other features can be added such as daily cleaning notification, updates about the efficiency of the solar panels, and so on. Mechanical structure can also be modified. A research can be done, to measure the efficiency of solar panels, in normal weather and in the availability of sun, humidity, etc., from this research, an additional feature can be added, such as the robot can sense automatically that the efficiency of solar panels has been decreased , weather is okay sun is available and all desired parameters are also right in that case the robot has to start cleaning without any instruction. Parachute fabric brush can be replaced with an other brush for removing thick dust.

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ANNEXURE

Annexure-A

Activity plan for final year design project.

Annexure-B

Graduate attributes/Programming learning outcomes.

Annexure-C

Washington accord knowledge profile.

Annexure-D

Sustainable development goals (SDGs).

Annexure-E

Complex engineering problem (CEP) attributes.

Complex engineering activities (CEAs).