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Solar-Shine: An IOT based Semi-Automated Solar Panel Cleaning Robot

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***Abstract*— Amidst the escalating challenges posed by climate change and global warming, the imperative for sustainable energy solution is paramount. The widespread deployment of solar panels for renewable energy generation has ushered in a new era of sustainable power. However, the pursuit of maximizing solar energy efficiency encounters a formidable obstacle — the need to maintain impeccably clean solar panels. Dust, dirt, and environmental pollutants accumulate, hampering solar panel effectiveness and resulting in a decline in energy output. In response, this project addresses the problem through the development of Solar-Shine, a semi-automated solar panel cleaning robot. Equipped with dual mode switch, it seamlessly transitions between manual and automatic modes. The incorporation of microfiber technology replaces conventional brushes, enhancing cleaning precision and sustainability. Additionally, a water sprayer mechanism, coupled with an onboard water tank, ensures thorough cleansing of solar panels. The robot operates remotely, minimizing risks to workers and offering wireless control for optimal safety. While designed primarily for large scale solar power plants, its versatility extends to various settings, including residential and commercial rooftop solar panels. The integration of robotics into solar maintenance represents an innovative solution for the renewable energy sector, enhancing the sustainability and reliability of solar power systems.**

***Index Terms*— Energy efficiency, IOT, Microfiber, Solar panels, Sustainable energy, Renewable energy, Robotics**

I. INTRODUCTION

In the ever-evolving landscape of renewable energy, solar power has emerged as a pivotal contributor to sustainable energy generation. As solar energy gains prominence, the importance of maintaining peak efficiency in solar panels becomes evident. The accumulation of environmental debris poses a substantial hurdle to optimal solar panel performance. This research delves into a solution that goes beyond traditional cleaning methods, introducing an innovative approach through the development of Solar-Shine, therefore highlighting the need for more advance and efficient cleaning technologies to address the evolving challenges faced by solar power plants. The literature review explores the current state of research in the field, providing a comprehensive overview of existing studies and key findings. Deshmukh et al. present a solar panel cleaning robot, CLEAROSO, highlighting its development with Arduino-based control, rechargeable batteries, and motorized movements. The results indicate a substantial 50% boost in solar panel power output post-cleaning, underscoring the robot's efficiency [1]. Manju et al. present a project focusing on the design and implementation of a microcontroller-based dust cleaning system for solar panels. The study aims to establish an automatic mechanism for efficient solar panel cleaning. [2].

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Sairaj and Reddy introduce an automatic cleaning mechanism, employing a PIC 16F1527 microcontroller to control a stepper motor, air compressor, and water pump for efficient cleaning of solar panels. Utilizing gantry-driven mist nozzles, the system provides automated cleaning using pressurized air and water based on the level of dust accumulation [3]. Olorunfemi et al.'s systematic review examines the effectiveness of smart systems in detecting and cleaning solar panel dirt, emphasizing real-time monitoring for improved power output and remote-control capabilities. The study highlights a critical limitation in the insufficient empirical analysis of existing smart systems [4]. Derakhshandeh et al.'s review categorizes solar panel cleaning systems into active and passive groups, providing a detailed comparison of features, including cost, efficiency, water usage, cleaning time, and human interference. The paper recommends electrostatic cleaning for water-scarce regions but advises against robotic systems in windy climates due to operational limitations [5]. Parrott et al. present a study on the efficacy of an automated robotic cleaning system, featuring a silicone rubber foam brush, for dry cleaning solar panels and increasing power output without causing damage, highlighting its promise for cost-effective solar panel dust mitigation [6]. Antonelli et al. describe an autonomous, rail-free robotic device for waterless dust removal from photovoltaic panels. Operating as a half-track, the robot utilizes helical brushes, ultrasonic sensors, and an ARDUINO DUE platform for real-time control, showcasing effectiveness in autonomous motion, dust removal, and low power consumption during experimental tests [7]. Dhanalakshmi et al. propose a solution to address limitations by introducing a remote-control-based robot for solar panel cleaning. Utilizing Arduino and Bluetooth technology, this automated system, operated via mobile phones, offers a compact and efficient alternative, reducing both time and manpower, particularly beneficial for large-scale solar panel units [8]. Akyazi et al. introduce a solar panel cleaning robot (SPCR) featuring a dual-motor and crawler design, with horizontal movement and a vertically operating cleaning brush. Real-time testing validates its functionality, and the robot is equipped with position switches for detecting the length of the solar panel array, ensuring precise operation within the desired working area [9]. Chakaborty et al. propose a contemporary solution to labor-intensive solar panel cleaning by introducing a remote-controlled robot operated through mobile phones. Utilizing Arduino and Bluetooth technology, this autonomous robot offers compactness, time savings, and efficiency, particularly suited for large-scale solar panel systems [10]. Laksahani et al. propose a solar panel cleaning mechanism tailored for coastal areas, featuring a guided cleaning path ensuring thorough cleaning using minimal water. The design incorporates a cleaning unit with a roller brush, detergent supply, and wiper, and a locomotion unit providing both vertical and horizontal motion. This system optimizes solar panel performance, minimizes human involvement, and reduces cleaning costs [11]. Alzarooni et al. detail the design and implementation of an automated dry solar panel cleaning system, emphasizing cost-effectiveness. The system employs microfiber brushes, DC motors for cleaning and movement, ultrasonic sensors for edge detection, and a microcontroller with relays for control. Powered by a 12V lead acid DC battery, the system operates without using liquids, providing an efficient and low-cost solution for solar panel cleaning [12]. Aravind et al. present an autonomous robotic vacuum cleaner with a two-stage cleaning process for efficient solar panel maintenance. The system includes a docking station, utilizes a feedback mechanism for navigation, and automatically returns to recharge from the solar panels when the battery voltage is low, offering a cost-effective and robust solution for cleaning and recharging interconnected solar panel arrays [13]. Patil et al. provide a comprehensive review of automated cleaning mechanisms for solar photovoltaic panels, covering electrical, mechanical, chemical, and electrostatic techniques. The study aims to identify research gaps in automated cleaning systems, offering insights into recent developments and addressing the dust problem in solar photovoltaic modules [14]. Jawale et al. introduce a novel design for a human-portable robotic cleaning system for solar panels, maneuvering on glass surfaces at varying angles. Utilizing the Arduino Uno R3 microcontroller board, the system controls devices and assesses efficiency changes resulting from solar panel array cleansing, offering an innovative approach to enhance efficiency [15]. Sorndach et al. create a solar panel cleaning robot with omni-wheels, allowing free rotation during operation. The robot's drive system facilitates climbing inclined and slippery panels, and sensors ensure accurate movement. Results reveal successful navigation on 10° inclined panels, with a 64%-time savings in cleaning by utilizing rotating movement instead of turning after 12 meters of cleaning distance [16]. Kumar and Murthy introduce a solar-powered PV panel cleaning robot designed to autonomously clean surfaces by blowing air, spraying liquid, wiping with a brush, and drying. Controlled remotely via the Internet of Things (IoT), the self-powered robot reduces human effort in solar plants and enhances power generation efficiency through periodic cleaning [17]. Yerramsetti et al. introduce an AI-driven automatic robot for efficiently cleaning floating solar panels. Overcoming the challenges of manual cleaning, the robot utilizes gear motors and a cleaning membrane, with a camera monitoring panels and uploading data to cloud storage for damage and cleaning references, enhancing overall efficiency [18]. Khadka et al. discuss current practices and future prospects of solar photovoltaic panel cleaning systems. Highlighting the impact of factors like soiling on performance, the paper suggests a decision-making model integrating data science and machine learning for optimal cleaning interventions in solar PV systems, emphasizing potential advancements in renewable energy [19]. Jaradat et al. propose a fully portable robotic cleaning system using an Arduino microcontroller. The versatile platform travels the entire length of a solar panel, providing favorable initial testing results. The study concludes that such robotic cleaning solutions are practical for maintaining clean PV panel efficiency, with discussions on future design improvements [20]. Ronnaronglit and Maneerat design and develop Solar Panel Cleaning Robots for efficient operation in Thailand. Utilizing Wireless Joystick, Sensor Sonar, Gear Motor, and an ARDUINO microcontroller, the robot employs a rotary brush with water spray, achieving an 80% cleaning efficiency on solar panels with a surface level of 0-30 degrees Celsius [21]. Hashim et al. present a study on a solar panel cleaning robot that employs robotics technology to enhance efficiency. The proposed strategy involves monitoring power generation and cleaning the photovoltaic surface as needed through a mobile app. The study confirms the practicality of the proposed design through enhancements achieved by the unique structure and developed model [22]. Khadka et al. present an IoT-based model, the Smart Solar Photovoltaic Cleaning System, designed for large-scale solar plants in semi-arid areas with frequent cleaning needs due to sand deposition. The paper emphasizes the importance of a cost-based economic analysis to ensure a viable investment based on plant size, location, and environmental conditions [23]. Jaiganesh et al. address the challenge of dirt accumulation on solar PV panels, reducing sunlight penetration and diminishing efficiency. Various cleaning techniques, including manual and vacuum cleaning, have drawbacks such as manpower requirements and potential panel damage. The authors propose an Automatic Wiper Cleaning system using Arduino to mitigate these issues and enhance the efficiency of solar PV panels, aiming for a 15–20% increase in efficiency [24]. Sarode et al. conduct a comprehensive review on the challenges posed by dust, mist, bird droppings, and snow on PV solar panels' efficiency. They highlight the drawbacks of manual cleaning, including non-uniformity, inaccessibility, and the risk of damage and human casualties. The paper advocates for automated robotic cleaning solutions to address these issues, offering a detailed review of technologies developed globally for this purpose [25]. Jadhao et al. conduct a study on the impact of different solar panel cleaning methods on performance. The paper explores various cleaning techniques, including natural cleaning, manual washing, brushing, wind blowing, automated mechanical cleaning, water spraying, ultrasound vibration, microcontroller-based automatic cleaning, electrostatic cleaning, superhyperbolic coating, and superhydrophilic coating. The review aims to assist in selecting the most suitable cleaning method for PV panels [26].

A comprehensive review of existing literature reveals a growing interest in solar panel maintenance, predominantly focused on manual cleaning methods and automated systems. While manual cleaning is effective, it often proves labor intensive and impractical for large scale solar farms. Some automated systems exist, but they often lack sophistication needed to adapt to diverse environmental conditions. Solar-Shine bridges this gap by offering a smooth transition between manual and automatic modes, leveraging microfiber technology and incorporating a water sprayer mechanism and remote operation. These features contribute to the originality of the proposed solution, marking a significant advancement in solar panel maintenance technology.

II. METHODOLOGY

In developing our semi-automated solar panel cleaning system, the ATmega328P microcontroller serves as the computational core, offering an 8-bit AVR architecture, 5V operation, and versatile I/O options (6 A0 – A5 analog pins, 14 digital I/O pins with 6 PWM outputs). With 32 KB Flash Memory, 2 KB SRAM, and 1 KB EEPROM, running at 16 MHz, it supports IIC, SPI, and USART communication. For wireless connectivity and reliable data transfer, the HC 05 Bluetooth module is utilized, operating at 2.4GHz. The 65mm robot wheel, made of high-strength plastic with a rubber tire, ensures stability and durability for effective movement. The HC-SR04 ultrasonic sensor, operating at 5V with a 2-400 cm range, is essential for obstacle detection, featuring a frequency of 40 KHz. The DC water pump operates between 6-12V, with a working current of 0.5-0.7A, suitable for fluid handling in the cleaning process. The microfiber roller, made from a blend of polyester and polyamide(nylon) fibers, creates a fabric with unique properties, including softness, durability and exceptional absorbency and covers an optimal cleaning width of 15 cm. The relay module, with a trigger voltage of 5V and a trigger current of 20 mA, controls high-power devices, featuring a maximum switching voltage of 250VAC@10A or 30VDC@10A in SPDT configuration. The L293d motor driver accommodates a wide supply voltage range (4.5V to 12V), ensuring smooth and accurate motor operations. The 100 RPM DC motor operates at 3-12V, with a shaft length of 8.5 mm and a shaft diameter of 5.5 mm (Double D-type). It has a no-load current of 40-180mA, a rated speed of 100 RPM (after reduction), and a rated torque of 0.35 Kg-cm. A 9-volt battery ensures a reliable and uninterrupted power supply for the robot. Additional structural components such as mounts, couplings, and a supporting frame contribute to overall stability during the robotic system's operation. A fully assembled model is shown in Fig. 3.

The block diagram in Fig. 1 illustrates the interconnected components of the Solar Shine robotic system, showcasing their collaborative functionality. Atmega328p microcontroller serves as the central hub orchestrating the collaborative functionality of various components. It communicates with the Bluetooth module to receive commands for remote control and interacts with the ultrasonic sensor to gather distance data for obstacle detection. The Atmega328p then utilizes the L293D motor driver to control the DC motors connected to wheels, enabling the robot's movement. The 9-volt battery serves as the primary source for the entire system, while the relay module efficiently manages power distribution to different components, enhancing overall energy utilization. As the robot navigates, the ultrasonic sensor constantly provides feedback to the Atmega328p, allowing it to make real-time decisions for obstacle avoidance. When engaged in cleaning, the microcontroller activates the DC water pump to distribute water for efficient cleaning, and it controls the microfiber roller's rotation to ensure thorough coverage of the solar panels. This collaborative functionality ensures a seamless operation where the robot can be remotely controlled, navigate intelligently, and perform effective solar panel cleaning.

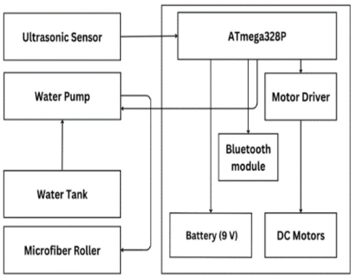

Fig. 1: Block diagram for designed semi-automated system

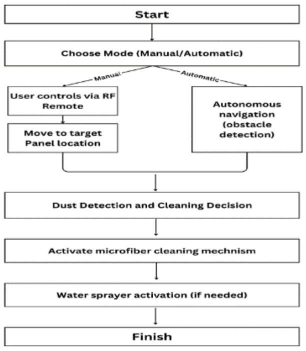

Fig. 2: Flowchart showcasing the working procedure of the robot

The flowchart in Fig. 2 outlines the working procedure of the solar panel cleaning robot. It begins with the power-on state, followed by mode selection (manual or automatic). In manual mode, user commands from the RF remote dictate movement and cleaning actions, allowing for precise control over the robotic system. In automatic mode, the system employs Sonar Sensors to autonomously navigate and clean solar panels, ensuring efficient obstacle detection and avoidance. The microfiber roller, activated by DC Motors, ensures precise and efficient cleaning. The water sprayer mechanism, involving the water tank with a motorized pump, complements the cleaning process for effective and sustainable maintenance. The operational control, facilitated by the ATmega328P Controller Circuitry and HC-05 Bluetooth module, allows for seamless transitions between manual and automatic modes.

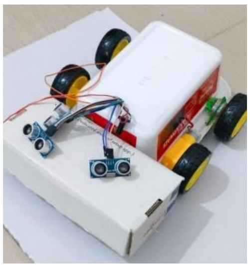

Fig. 3: Proposed Model

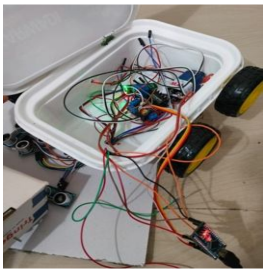

Fig. 4: Model Circuit

III. Results And Discussions

To evaluate the effectiveness of the solar-shine robot, an experiment was conducted simulating real-world conditions. The experiment involved applying a controlled amount of flour to mimic common environmental dust accumulation on solar panels. The robot, operating in automatic mode, navigated the panel surface, and the cleaning performance was visually observed. The robot demonstrated efficient cleaning capabilities, effectively removing the flour particles from the solar panel. Fig. 5 illustrates the experimental setup. Additionally, a comparison of solar panel voltages (illustrated in Table 1) was conducted before dust accumulation, during dust presence, and after cleaning on a specific day at various timings. It allows for the analysis of how dust accumulation impacts solar panel performance and how effectively the cleaning system mitigates this impact.

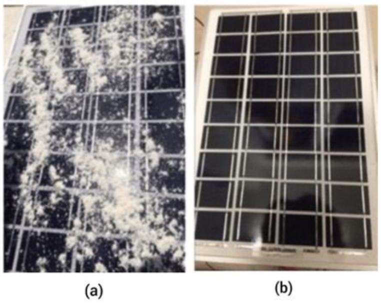

Fig. 5. (a) Solar panel covered with dust (flour), (b) Cleaned solar panel using developed robot prototype [27]

TABLE I. COMPARISON OF SOLAR PANEL VOLTAGES BEFORE AND AFTER CLEANING [27]

Time	P (W)		
	Before Dust	During Dust	After Cleaning
11.00 am	2597.85	1035.65	2561.10
12.00 pm	2742.76	1083.89	2786.90
13.00 pm	2713.62	1098.90	2734.30
14.00 pm	2756.00	1039.60	2543.03

From the results, it can be observed that the proposed system is efficient in maintaining and restoring optimal solar panel output, thus highlighting the practicality and effectiveness of the robot in addressing the challenges of solar panel maintenance. The robot's dual-mode operation, microfiber technology, and sustainable water usage position it as a valuable and advantageous solution for large-scale solar farms, such as the Canal Top Solar Power Project in Gujrat, demonstrating its potential impact on enhancing solar panel efficiency. The results affirm the robot's effectiveness in reducing labor, time, and water consumption compared to traditional cleaning methods.

IV. FUTURE SCOPE

Solar-Shine robot holds promising avenues for advancement including the integration of machine learning for adaptive navigation and advanced sensor technologies for enhanced safety. Additionally, exploring alternative cleaning mechanisms and materials may increase precision and longevity. Further research could also focus on improving remote monitoring through IoT technologies, enabling real-time operational insights and proactive maintenance planning.

V. CONCLUSION

The proposed solar panel cleaning robot represents a significant advancement in solar panel maintenance technology, offering an innovative solution to the persistent challenges related to solar panel cleaning. By combining the cutting-edge features, this robot emerges as a transformative tool in the pursuit of sustainable and reliable solar power systems. Furthermore, the identified challenges and future scope outlined in this study present exciting opportunities for further research and development in the field of renewable energy, thus contributing to the ongoing evolution of solar energy systems on a global scale.

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