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Robotics in Solar Energy: Enhancing Panel Efficiency through Robotic Cleaning

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Abstract - *Solar energy is a crucial renewable resource, but the efficiency of solar panels can be significantly reduced due to the accumulation of dust and debris on their surface. Regular cleaning is necessary to maintain optimal energy output, especially in regions prone to dust. This paper presents the development of a solar panel cleaning system aimed at improving the generation of required units of energy and longevity of solar installations. The proposed solution involves a robot, controlled by microcontroller, designed to provide a cost-effective and efficient cleaning method. The paper explores the overall design considerations, the need for such systems, and the environmental and energy benefits of maintaining clean solar panels. Additionally, it highlights the challenges faced while developing this system.*

Key Words: **Solar energy, renewable resource, solar panels, efficiency, dust accumulation, optimal energy output, solar panel cleaning system, robot, microcontroller, cost-effective, efficient cleaning, energy benefits, solar panel maintenance**.

1.INTRODUCTION

The increasing global demand for clean and sustainable energy has made solar power one of the most viable and widely adopted renewable energy sources. Solar panels, which convert sunlight into electricity, play a pivotal role in harnessing this energy. However, the efficiency of solar panels is highly dependent on their cleanliness. Dust, dirt, and other environmental pollutants accumulate on the surface of solar panels, reducing their ability to absorb sunlight and generate electricity. Figure 1 depicts solar panel with dust and an actual clean solar panel. Studies have shown that in regions with high dust levels, energy losses due to soiling can reach up to 30%, leading to significant reductions in power generation.

Manual cleaning of solar panels is time-consuming, labor-intensive, and can be inefficient, especially for large-scale solar farms. Furthermore, improper cleaning techniques can damage the delicate surface of the panels, reducing their lifespan. As a result, there is a growing need for automated, efficient, and cost-effective solutions to maintain solar panel cleanliness and ensure maximum energy output.

This paper introduces a Solar Panel Cleaning Robot, controlled by a PIC18F4520 microcontroller, designed to address this need. The robot offers a remote-controlled solution for regular cleaning of solar panels, with minimal human intervention. This approach not only improves the efficiency of solar installations but also reduces the overall maintenance cost. The following sections of this paper discusses the system architecture, key components, design challenges, and future directions for the development of this technology.

Fig-1: Clean Solar panel and panel with dust

2. LITERATURE REVIEW

The electric strength produced with the aid of photovoltaic cells relies upon sun irradiance falling at the top of the panel. To maximize the publicity of photovoltaic cells to solar irradiance, sun voltaic cells are installed out of doors. In outdoor environment, dust starts to accumulate at the floor of photovoltaic panels and as end result reduces the effective solar irradiance falling at the floor of photovoltaic panels. Further, different fowl droppings, ice, and salt layer on photovoltaic panels additionally obstruct sun irradiances falling on solar panel. To address these troubles, cleaning structures for photovoltaic cells are used.

the study by Laksahani et al. (2021), *"Design Mechanism for Solar Panel Cleaning Process"*, contributes valuable insights into designing efficient cleaning mechanisms for solar panels. It highlights the optimization of cleaning processes to address dust and dirt accumulation while ensuring mechanical stability and operational safety. It provided a foundation for designing the cleaning mechanism for our robot, helping us understand critical design considerations and implement effective solutions.[4]

'Modeling, simulation, and experiments of a flexible track robot over rigid horizontal and inclined surfaces' by N. Ezra, A. Cohen, and D. Zarrouk provided valuable insights into the challenges and dynamics of robot movement on horizontal and inclined surfaces. This study informed the design and movement control strategies for our solar panel cleaning robot, particularly in overcoming surface irregularities and ensuring stability on inclined panels. The modeling and simulation techniques described were instrumental in refining our approach to motor control and ensuring uniform cleaning performance.[1]

Thangarasu et al. (2024) proposed an Arduino-based cleaning system that integrates automation to enhance energy efficiency. This approach underscored the role of microcontroller-based designs in achieving precise control and low power consumption, which aligns with our choice of control mechanisms [2].

Similarly, Sarode et al. (2023) reviewed various solar panel cleaning robot technologies, emphasizing the importance of mechanical simplicity and effective cleaning techniques. Their findings guided the selection of practical and efficient cleaning methods [3].

Noh et al. (2020) demonstrated a solar panel cleaning robot powered by Arduino, focusing on design simplicity and cost-effectiveness. This work provided a foundation for integrating motor control into our robot [5].

Hashim et al. conducted a study focusing on intelligent robotic systems for solar panel cleaning. Their research emphasized optimizing the cleaning process to reduce operational costs and improve long-term panel efficiency. The robot developed in their study utilized sensors and an intelligent control system to enhance cleaning precision. Their work demonstrated how automation, paired with smart technologies, could offer a cost-effective and reliable solution for maintaining solar panel cleanliness, even in large-scale solar farms.[7]

Ronnaronglit and Maneerat (2019) developed a cleaning robot specifically for solar panels, which offered insights into practical implementation and the importance of field testing in real-world environments [8].

Sorndach et al. (2018) designed a solar panel cleaning robot using omni wheels, which allowed it to move easily on tight or small rooftop spaces. This made it more flexible and efficient for cleaning panels in areas with limited space [10]. By incorporating similar considerations, our project ensured efficient navigation and cleaning on uneven or restricted surfaces.

Unlike other existing solar panel cleaning systems, our design focuses on providing a cost-effective solution by utilizing the PIC18F4520 microcontroller, known for its affordability and efficiency. Additionally, our robot can be operated through a Bluetooth module (HC-05), allowing for remote control without complex infrastructure. Another distinctive feature is its ability to function on slopes up to 30 degrees, making it adaptable to a variety of installation environments, including inclined rooftops and uneven terrains.

3. METHODOLOGY

The proposed solar panel cleaning robot is used to remove the dirt and dust deposited on the solar panel thus helping the solar panel to absorb the maximum quantity of energy. To achieve the goals, we implemented a structured approach that focuses on designing a low-cost, efficient, and adaptable solar panel cleaning robot. The following

methodology outlines the key stages of development, from system design to testing and validation.

System Design: The solar panel cleaning robot is designed to be low-cost and adaptable to various panel installations, including those with up to 30-degree slopes. The robot uses a PIC18F4520 microcontroller as the control unit due to its cost efficiency and reliable performance [2].

Mechanical Structure: The robot is built with lightweight materials to ensure smooth movement on the solar panels without causing any damage [1]. The structure consists of a frame mounted with soft cleaning brushes that effectively remove dust and debris from the surface. The frame is designed to traverse the panels both horizontally and vertically to ensure full coverage [3].

Control System: The PIC18F4520 microcontroller controls the robot's motors, which drive the cleaning brushes and the robot's movement along the panel surface. The movement is controlled by sending signals to the motors that drive the robot across the surface in predefined patterns. The vertical and horizontal motions are driven by separate motor units to ensure efficient cleaning.

Bluetooth Communication: The robot is equipped with an HC-05 Bluetooth module, allowing users to control the robot remotely using a mobile device. Through a custom-designed app or direct Bluetooth communication. Here we are using serial Bluetooth terminal app. Users can start, stop, or manually control the robot's movement across the panels.

Motor-driving mechanism: The motor driving mechanism for this solar panel cleaning robot incorporates five DC motors, with 4 motors operating at 100 RPM for wheels movement and one at 60 RPM for cleaning brush movement. These motors are controlled using two L293D motor drivers. The L293D motor driver is a dual H-bridge IC it allows bi-directional control of the motors, making it ideal for this robot's operations by enabling precise forward and reverse movements. One motor driver is dedicated to controlling the movement of the cleaning brush, ensuring consistent cleaning across the solar panel surface. The other driver regulates the motors responsible for wheel movement, enabling smooth navigation of the robot [5].

Water Pump and Water Tank: To enhance cleaning effectiveness, a DC water pump is integrated into the system. The pump draws water from an onboard water tank, which is mounted securely on the robot's chassis. Controlled via the microcontroller, the water pump ensures consistent water flow to aid in cleaning stubborn dirt and grime.

Power Supply: The robot is powered by a rechargeable battery that ensures sufficient operation time for cleaning a large array of panels. The system is designed to operate on a fully charged battery, and provisions are made to recharge the battery between operations.

Slope Handling: To address the challenge of cleaning solar panels installed on slopes, the robot is designed to operate effectively on surfaces inclined up to 30 degrees. This is achieved by adjusting the torque of the motors and using grip-enhancing wheels, ensuring the robot can maintain traction and stability while cleaning [1].

Testing and Validation: The prototype was tested under different conditions, including varied panel inclinations and dust accumulation levels. Performance metrics such as cleaning efficiency, battery life, and communication range were evaluated to ensure optimal operation. The ability to navigate slopes and maintain cleaning performance was specifically tested to validate the robot's adaptability to sloped installations.

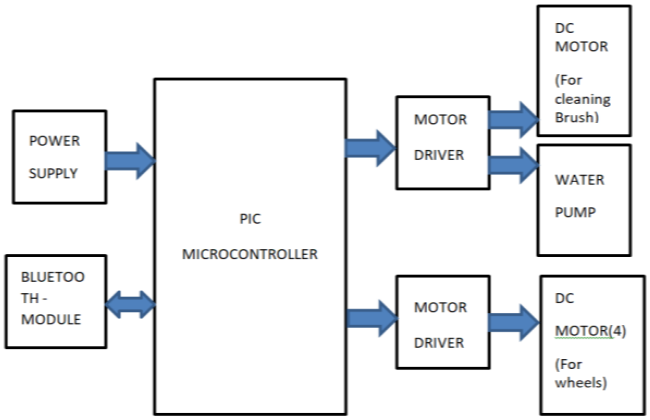

Fig-2: Block diagram of Solar Panel Cleaning Robot

The given fig 2. illustrates the functional layout of a solar panel cleaning robot. The system is powered by a dedicated power supply and controlled by a PIC microcontroller. It incorporates total 5 DC motors, 4 DC motors operating at 60 RPM to manage the movement of wheels and 1 DC motor operating at 60 RPM to manage cleaning functions. These motors are controlled through two L293D motor drivers, with one driver dedicated to the cleaning brush and water pump and the other to the wheel motors. The water pump ensures consistent water flow to aid in cleaning stubborn dirt. The Bluetooth communication module (HC-05) facilitates wireless control, allowing commands to be sent from a smartphone using the Serial Bluetooth Terminal app.

4. IMPLEMENTATION

The solar panel cleaning robot integrates efficient hardware and software systems. The PIC18F4520 microcontroller, programmed in Embedded C, controls

motors, water flow, and Bluetooth communication. Its lightweight frame with soft brushes ensures safe cleaning, with a design supporting horizontal and vertical movement for full coverage.

The robot uses five DC motors (four 60 RPM for wheels, one 100 RPM for the brush) managed by two L293D motor drivers. An HC-05 Bluetooth module allows remote operation via a serial app. A DC water pump connected to an onboard tank ensures consistent water flow, controlled by the microcontroller. It is powered by a rechargeable battery, it handles slopes up to 30 degrees with high-torque motors and grip-enhancing wheels.

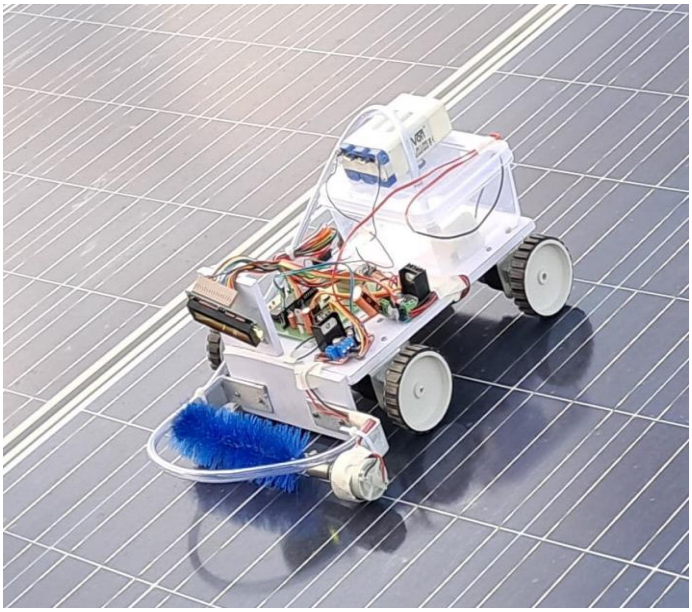

Fig-3: Final prototype

5. RESULT AND ANALYSIS

Fig-4: Outdoor Testing

As figure 3 depicts in outdoor testing solar panel cleaning robot demonstrated its ability to efficiently clean dust and other debris from panel surfaces, leading to improved energy output. Cleaning trials showed significant improvement in panel performance.

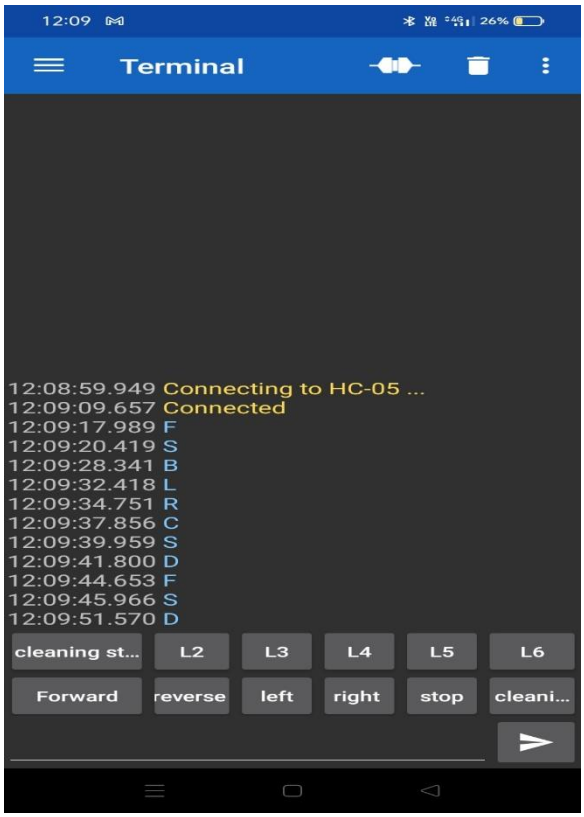

Fig-5: Commands on serial Bluetooth control app

We controlled the movement of the solar panel cleaning robot using the HC-05 Bluetooth module, which facilitates wireless communication between the robot and a smartphone. As depicted in fig 4. Serial Bluetooth Terminal app, available on Android devices is used. It serves as the interface for sending control commands. Through this app, serial commands are transmitted to the HC-05 module, which communicates with the robot's microcontroller. The commands like forward, reverse, left, right, stop, cleaning start, cleaning stop are provided and for each command specific letters like F (Forward), S(stop), B(Backward) are used. The microcontroller processes these commands to control the motor drivers, enabling precise control of the robot's movements.

Fig -6: Cleaning on steep slopes

Challenges faced: As fig 5. depicts, the varying inclination of panels posed challenges for maintaining stability and achieving consistent cleaning pressure. Adjustment in wheel alignment were required to handle steep and uneven panel angles effectively. The robot showed promising results in improving panel efficiency and reducing manual efforts of cleaning solar panels.

6. CONCLUSION

The solar panel cleaning robot successfully removed accumulated dust and dirt, leading to a noticeable recovery in panel performance. Pre-cleaning assessments showed that dust reduced energy output by 15-20%, but after the robot's operation, the panels reached close to their peak efficiency, achieving around 98% of optimal output. This demonstrates the robot's capability to significantly enhance energy production by addressing one of the primary challenges faced by solar installations—dust accumulation.

Field trials highlighted that the robot provided consistent cleaning across the entire surface, effectively addressing challenges typically faced with manual methods, such as uneven cleaning or difficulty accessing certain areas. Its movement ensured no part of the panel was left untreated, delivering uniform results that manual cleaning often fails to achieve. This uniform cleaning approach also helped reduce wear on the panels and improved long-term performance by avoiding localized buildup of debris, which can otherwise lead to efficiency losses over time. By simplifying the cleaning process, the robot not only improved operational efficiency but also proved to be a practical solution for maintaining solar panels, particularly in installations with challenging accessibility or larger arrays.

REFERENCE

[1] Ezra, N., Cohen, A., & Zarrouk, D. (2024). Modeling, simulation, and experiments of a flexible track robot over rigid horizontal and inclined surfaces. *Mechanism and Machine Theory, 199*, 105689.

[2] Thangarasu, S. K., Gobinath, V. K., Shanmugam, A., Mathan Kumar, S., Shrinidhi, K. M., & Sanjay, S. (2024). Innovative Arduino-based solar panel cleaning system for enhanced energy efficiency. In *2024 15th International Conference on Computing Communication and Networking Technologies (ICCCNT)* (pp. 1-5). IEEE.

[3] Sarode, N., Ghugal, P., Yadav, S., Dantule, S., & Nandankar, P. (2023). A comprehensive review on solar panel cleaning robot technologies. In *AIP Conference Proceedings, 2753*(1). AIP Publishing.

[4] Laksahani, U. C., Udithamala, W. B. I., Chathurani, T. D. K. U., & Yasakethu, S. L. P. (2021). Design mechanism for solar panel cleaning process. In *2021 10th International Conference on Information and Automation for Sustainability (ICIAfS)* (pp. 82-87). IEEE.

[5] Noh, F. H. M., Yaakub, M. F., Nordin, I. N. A. M., Sahari, N., Zambri, N. A., Yi, S. S., & Saibon, M. S. M. (2020). Development of solar panel cleaning robot using Arduino. *Indonesian Journal of Electrical Engineering and Computer Science, 19*(3), 1245-1250.

[6] Akyazi, O., Sahin, E., Ozsoy, T., & Algul, M. (2019). A solar panel cleaning robot design and application. *Avrupa Bilim ve Teknoloji Dergisi*, 343-348.

[7] Hashim, N., Mohammed, M. N., Selvarajan, R. A., Al-Zubaidi, S., & Mohammed, S. (2019). Study on solar panel cleaning robot. In *2019 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS)* (pp. 56-61). IEEE.

[8] Ronnaronglit, N., & Maneerat, N. (2019). A cleaning robot for solar panels. In *2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST)* (pp. 1-4). IEEE.

[9] Park, H., Öztürk, A., Park, H., & Khan, M. U. (2019). Utilization of robotics for solar panel cleaning and maintenance. *Konya Journal of Engineering Sciences, 7*(4), 768-775.

[10] Sorndach, T., Pudchuen, N., & Srisungsitthisunti, P. (2018). Rooftop solar panel cleaning robot using omni wheels. In *2018 2nd International Conference on Engineering Innovation (ICEI)* (pp. 7-12). IEEE.