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Review on Solar Panel Cleaner Robot

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Abstract:
Dust and environmental pollutants greatly reduce the efficiency of solar photovoltaic systems, causing energy loss and increasing maintenance needs. Many studies have shown that dust has a strong negative effect on panel performance, making regular cleaning necessary. Although automated and robotic cleaning systems exist, most of them work on fixed schedules and do not use intelligent decision-making or real-time monitoring. In the same way, IoT-based systems are useful for tracking performance but usually do not include cleaning mechanisms, while AI-based methods mainly focus on prediction and are not connected with robotic systems.
Keywords : *Solar Panel , IOT, AI, Embedded System, Real-time.*

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I. INTRODUCTION

This paper focuses on the design and development of an IoT-enabled solar panel cleaning robot using the ESP32-WROOM (38-pin) microcontroller, aimed at improving solar energy efficiency through automated, intelligent maintenance. The system integrates a water sprinkling mechanism and a motordriven rotational mop to remove dust, bird droppings, and other surface contaminants that significantly reduce photovoltaic output. The ESP32 serves as the central controller, managing motor drivers, relay-based water control, and real-time sensor data acquisition while also providing built-in Wi-Fi connectivity for cloud communication.

To enhance operational intelligence, the project incorporates an AI-based predictive analytics module that determines the optimal cleaning schedule for solar panels. Instead of relying on fixed-interval cleaning, the system analyzes multiple parameters such as historical power output trends, environmental factors (dust accumulation patterns, temperature, humidity, and weather conditions), and cleaning history. These parameters are processed using machine learning models to forecast soiling levels and predict when cleaning is necessary, thereby reducing water usage, energy consumption, and unnecessary mechanical wear. A web-based monitoring and analytics dashboard is developed to provide realtime visibility and control over the system. The dashboard displays live sensor data, cleaning status, energy efficiency metrics, and AI-generated cleaning recommendations. Users can remotely trigger cleaning cycles, modify operational thresholds, and review historical performance data through graphical analytics. By combining IoT automation, mechanical cleaning mechanisms, and AI-driven forecasting, this project delivers a scalable, costeffective, and sustainable solution for maintaining solar panel efficiency, making it suitable for both residential and large-scale solar installations.

II. LITERATURE SURVEY

[1]. Effect of Dust Accumulation on the Performance of Solar Panels

The paper titled *"Effect of Dust Accumulation on the Performance of Solar Panels"* by A. Sayyah et al. (2014) investigates how dust deposition affects the efficiency of photovoltaic (PV) systems through PV performance analysis and environmental studies. The authors found that dust accumulation can significantly reduce the efficiency of solar panels, with losses reaching up to 40% under certain conditions. However, a key limitation of the study is that it does not propose or evaluate any cleaning mechanism to mitigate this problem. Despite this, the findings are highly relevant, as they clearly highlight the critical need for regular and effective solar panel cleaning to maintain optimal performance.

The study clearly demonstrates that dust deposition on solar panels can reduce their efficiency by up to 40%, which is a major advantage of the research as it quantitatively highlights the severity of performance degradation due to environmental factors. This strong empirical evidence helps in understanding the importance of maintenance in solar energy systems. However, a key drawback of the study is that it does not propose or analyze any cleaning or mitigation mechanism to address dust accumulation. Despite this limitation, the research is highly relevant , as it underscores the necessity for regular and effective solar panel cleaning to ensure optimal energy output.

[2]. Impact of Dust on Solar Photovoltaic Performance

The paper titled *"Impact of Dust on Solar Photovoltaic Performance"* by M. Mani and R. Pillai (2010) presents an experimental analysis of the effects of dust accumulation on solar photovoltaic systems. The study reveals that the power output of solar panels drops significantly due to dust deposition, emphasizing the negative impact of environmental conditions on PV performance. However, a limitation of the research is that it suggests manual cleaning as the primary solution, which may not be practical or efficient for large-scale or remote installations. The findings are highly relevant, as they support the requirement for an automated solar panel cleaning mechanism to maintain consistent power generation and reduce maintenance efforts.

A main advantage of this study is its experimental approach, which provides clear and practical evidence that dust deposition leads to a significant drop in power output. This strengthens the reliability of the findings and helps quantify the real-world impact of dust on PV performance. However, a major drawback of the study is that it recommends manual cleaning as the solution, which can be labor-intensive, time-consuming, and inefficient for large-scale installations. Despite this limitation, the research is highly relevant, as it strongly supports the need for an automated cleaning solution to improve efficiency and reduce maintenance challenges.

[3]. Automatic Solar Panel Cleaning System

The paper titled *"Automatic Solar Panel Cleaning System"* published by IEEE in 2017 discusses the use of motors and a water spray system to automate the cleaning of solar panels. The study finds that automated cleaning significantly improves the efficiency of solar panels by reducing dust accumulation and maintaining cleaner surfaces. An advantage of this system is that it minimizes manual intervention and ensures regular cleaning, leading to better and more consistent performance. However, a key limitation is that it operates on a fixed time schedule, without considering real-time dust levels or environmental conditions. This drawback makes the system less efficient and flexible. The study is relevant, as it highlights the need for incorporating intelligent decision-making capabilities to optimize cleaning operations based on actual conditions.

A major advantage of this system is that automation reduces human effort and consistently improves solar panel efficiency by regularly removing dust and debris. The use of a water spray mechanism further enhances cleaning effectiveness compared to dry methods. However, a notable drawback of the system is that it operates on a fixed time schedule, which does not account for real-time dust accumulation or changing environmental conditions, potentially leading to unnecessary water and energy usage. Despite these limitations, the study is relevant as it exposes the lack of intelligent decision-making, thereby emphasizing the need for a smarter, condition-based automated solar panel cleaning solution.

[4]. Robotic Cleaning System for Solar Panels

The paper titled *"Robotic Cleaning System for Solar Panels"* by S. K. Bansal et al. (2018) focuses on the development of an automated system for cleaning solar panels using embedded systems and DC motors. The study highlights how the proposed robotic mechanism effectively reduces human effort and minimizes safety risks associated with manual cleaning. However, one of the main limitations of the system is the absence of efficiency monitoring, which restricts the evaluation of its performance. Despite this drawback, the research serves as an important foundation for the design and development of robotic cleaning systems.

The main advantage of this system is that it significantly reduces human effort and minimizes safety risks by eliminating the need for manual cleaning of solar panels. It also improves maintenance efficiency and supports consistent panel performance. However, the system has certain drawbacks, including the lack of efficiency monitoring, which makes it difficult to assess its cleaning effectiveness and overall performance. Additionally, limited automation features may restrict its adaptability to different panel sizes and environmental conditions. Despite these limitations, the study provides a strong foundation for robotic cleaning design.

[5]. IoT-Based Solar Energy Monitoring System

The paper titled *"IoT-Based Solar Energy Monitoring System"* by J. Lee et al. (2019) discusses the development of a solar monitoring system using Internet of Things (IoT) technology and cloud computing. The system enables remote access to real-time solar performance data, allowing users to monitor energy generation and system status efficiently from any location. One of its major advantages is improved system management through continuous data collection and analysis. However, a key limitation of this system is that it does not include any automatic cleaning mechanism, which may affect long-term panel efficiency due to dust accumulation. Despite this drawback, the study is highly relevant, as it provides valuable support for real-time monitoring and performance optimization.

The main advantage of this system is that it enables real-time and remote monitoring of solar energy data, allowing users to track performance, detect faults, and manage the system efficiently from any location. It also improves decision-making through continuous data storage and analysis on cloud platforms. However, the system has certain drawbacks, including the absence of an automatic cleaning mechanism, which can lead to

reduced panel efficiency over time due to dust and dirt accumulation. Additionally, dependence on internet connectivity and cloud services may affect reliability in remote areas. Despite these limitations, the study is highly relevant as it supports effective real-time monitoring and performance optimization.

[6]. Smart Solar Panel Monitoring Using IoT

The paper titled *"Smart Solar Panel Monitoring Using IoT"* by R. Kumar et al. (2020) presents an IoT-based system for monitoring solar panel performance using ESP32 microcontrollers, various sensors, and a web-based dashboard. The system enables online display of important parameters such as voltage, current, and power, allowing users to monitor solar panel performance in real time. One of its main advantages is easy accessibility of data through a user-friendly web interface, which improves system supervision and maintenance. However, a major drawback of the system is the lack of AI-based analysis, which limits advanced performance prediction, fault detection, and optimization. Additionally, the system relies on stable internet connectivity for continuous monitoring. Despite these limitations, the study is highly relevant as it supports the development of web-based monitoring panels and enhances real-time data visualization.

[7]. Machine Learning for Solar Panel Efficiency Prediction

The paper titled *"Machine Learning for Solar Panel Efficiency Prediction"* published in IEEE Access (2021) focuses on the use of artificial intelligence and machine learning algorithms to predict the efficiency degradation of solar panels. The study demonstrates that AI-based models can accurately analyze performance data and forecast efficiency loss over time, which helps in early fault detection and better maintenance planning. One of the main advantages of this approach is improved system reliability through predictive analysis and data-driven decision-making. However, a key drawback of the system is the absence of robotic integration, which limits its practical application in automated maintenance and cleaning operations. Additionally, the effectiveness of the model depends heavily on the availability of high-quality data. Despite these limitations, the research is highly relevant as it provides a strong foundation for developing an AI-based efficiency checker and enhancing overall system performance.

[8]. Autonomous Solar Panel Cleaning Robot

The paper titled *"Autonomous Solar Panel Cleaning Robot"* published in the International Journal of Robotics (2022) discusses the development of an autonomous robotic system for cleaning solar panels using robotics and sensor technologies. The study shows that autonomous movement and sensor-based navigation significantly improve the effectiveness and consistency of the cleaning process. One of the major advantages of this system is reduced human involvement and enhanced cleaning efficiency through automatic operation. However, a key drawback of the system is water wastage, which makes it less suitable for areas facing water scarcity. Additionally, the lack of intelligent decision-making limits optimized cleaning schedules. Despite these limitations, the research is relevant as it highlights the need for smart cleaning decisions and supports the development of more efficient and resource-conscious robotic cleaning solutions.

[9]. Smart Maintenance of PV Systems Using AI

The paper titled *"Smart Maintenance of PV Systems Using AI"* published in Elsevier Renewable Energy (2023) presents an intelligent maintenance system for photovoltaic (PV) systems using artificial intelligence, Internet of Things (IoT), and cloud computing technologies. The study demonstrates that smart alert mechanisms based on real-time data analysis significantly improve system maintenance by enabling early fault detection and timely corrective actions. One of the main advantages of this system is enhanced operational efficiency through automated monitoring, predictive maintenance, and centralized data management. However, a major drawback is the absence of a physical cleaning mechanism, which limits its ability to address performance losses caused by dust and environmental pollution. Additionally, reliance on digital infrastructure may affect performance in areas with poor connectivity. Despite these limitations, the research is relevant as it provides valuable insights into AI-driven maintenance strategies, which can be integrated with a physical cleaning system for improved overall performance.

[10]. AI - IoT Integrated Solar Panel Maintenance

The paper titled *"AI-IoT Integrated Solar Panel Maintenance"* published in Recent Research (2024) discusses an advanced maintenance system that combines artificial intelligence, Internet of Things (IoT), and web-based technologies for solar panel management. The study shows that integrated systems significantly improve overall performance by enabling real-time monitoring, intelligent analysis, and automated decision-making. One of the main advantages of this approach is enhanced efficiency through the coordination of data collection, analysis, and maintenance actions on a single platform. However, a major drawback of the system is its high complexity, which increases implementation cost, maintenance difficulty, and technical dependency.

Additionally, such complex systems may require skilled personnel for operation and troubleshooting. Despite these limitations, the research is highly relevant as it motivates the development of a simplified, user-friendly, and cost-effective integrated solution for solar panel maintenance.

III. CONCLUSION

The literature survey of the research papers clearly demonstrates that dust and environmental pollutants significantly reduce the efficiency of solar photovoltaic systems, making regular maintenance essential. Early manual cleaning methods were inefficient and unsuitable for large installations. Although automated and robotic systems improved cleaning efficiency, most lacked real-time monitoring and intelligent decision-making. IoT and AI-based systems enhanced performance tracking and prediction but rarely integrated with physical cleaning mechanisms. Recent integrated solutions improved system management but faced challenges such as high cost, complexity, and limited adaptability. Overall, existing systems fail to provide a simple, cost-effective solution combining automated cleaning, monitoring, and intelligence. Therefore, the aims to integrate robotics, IoT, and AI to deliver an efficient, scalable, and sustainable solar panel maintenance solution.

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