Design and implementation of an integrated sun tracking and autocleaning system for photovoltaic panels

Projeto e implementação de um sistema integrado de rastreamento solar e autolimpeza para painéis fotovoltaicos

Diseño e implementación de un sistema integrado de seguimiento solar y autolimpieza para paneles fotovoltaicos

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ABSTRACT
This paper explores the current research landscape and engineering challenges associated with photovoltaic (PV) systems, with a focus on two critical technologies: sun tracking and self-cleaning mechanisms. Solar panels often suffer from reduced efficiency due to suboptimal orientation and dust accumulation, both of which impede optimal energy generation. To address these issues, an integrated solution is proposed that combines sun tracking for enhanced solar absorption and self-cleaning technologies to maintain panel efficiency. The paper provides a detailed framework for the design and implementation of this dual-purpose system, including hardware components, control algorithms, and energy optimization strategies. Additionally, the proposed system’s performance is evaluated through data analysis, highlighting the potential for increased power output and reduced maintenance costs. This research aims to contribute to the development of more efficient and sustainable solar energy practices, promoting wider adoption of photovoltaic technology in diverse environments.

Keywords: Photovoltaic Panel. Solar Tracking. Automatic Cleaning System. Arduino Uno. L293D. Motors.

RESUMO

Este artigo explora o cenário atual de pesquisa e os desafios de engenharia associados aos sistemas fotovoltaicos (PV), com foco em duas tecnologias críticas: rastreamento solar e mecanismos de autolimpeza. Os painéis solares geralmente sofrem com eficiência reduzida devido à orientação abaixo do ideal e ao acúmulo de poeira, os quais impedem a geração ideal de energia. Para abordar essas questões, é proposta uma solução integrada que combina rastreamento solar para absorção solar aprimorada e tecnologias de autolimpeza para manter a eficiência do painel. O artigo fornece uma estrutura detalhada para o design e a implementação deste sistema de dupla finalidade, incluindo componentes de hardware, algoritmos de controle e estratégias de otimização de energia. Além disso, o desempenho do sistema proposto é avaliado por meio de análise de dados, destacando o potencial para aumento da produção de energia e redução dos custos de manutenção. Esta pesquisa visa contribuir para o desenvolvimento de práticas de energia solar mais eficientes e sustentáveis, promovendo uma adoção mais ampla da tecnologia fotovoltaica em diversos ambientes.

Palavras-chave: Painel Fotovoltaico. Rastreamento Solar. Sistema de Limpeza Automática. Arduino Uno. L293D. Motores.

RESUMEN

Este artículo explora el panorama de investigación actual y los desafíos de ingeniería asociados con los sistemas fotovoltaicos (PV), con un enfoque en dos tecnologías críticas: el seguimiento solar y los mecanismos de autolimpieza. Los paneles solares a menudo sufren una reducción de la eficiencia debido a la orientación subóptima y la acumulación de polvo, los cuales impiden la generación óptima de energía. Para abordar estos problemas, se propone una solución integrada que combina el seguimiento solar para una mejor absorción solar y tecnologías de autolimpieza para mantener la eficiencia del panel. El artículo proporciona un marco detallado para el diseño e implementación de este sistema de doble propósito, incluidos componentes de hardware, algoritmos de control y estrategias de optimización energética. Además, el rendimiento del sistema propuesto se evalúa a través del análisis de datos, destacando el potencial para aumentar la producción de energía y reducir los costos de mantenimiento. Esta investigación tiene como objetivo contribuir al desarrollo de prácticas de energía solar más eficientes y sostenibles, promoviendo una adopción más amplia de la tecnología fotovoltaica en diversos entornos.

Palabras clave: Panel Fotovoltaico. Seguimiento Solar. Sistema de Limpieza Automático. Arduino Uno. L293D. Motores.

1 INTRODUCTION

The integration of solar energy systems into the broader landscape of renewable energy has garnered significant attention, particularly in the context of sustainable development and climate change mitigation (RASHID *et al*.,2023). Central to this integration is photovoltaic (PV) technology, which converts sunlight directly into electricity using semiconductor materials (MOUHIB *et al*.,2022). This conversion process is fundamental to various applications, ranging from residential rooftop installations to large-scale solar farms, signifying its versatility and adaptability. The importance of PV technology lies not only in its ability to generate clean energy but also in its potential to enhance energy security and reduce dependency on fossil fuels (HOU *et al*.,2023). Furthermore, advancements in efficiency and cost-effectiveness continue to drive the adoption of photovoltaic systems globally, thereby playing a crucial role in reducing greenhouse gas emissions and promoting environmental sustainability (GIELEN *et al*.,2019). As such, understanding the intricacies of PV technology is essential for the successful design and implementation of innovative systems, such as those incorporating sun tracking and autocleaning mechanisms (KASSEM *et al*.,2023).

Deserts, which provide vast areas of uninterrupted sunlight, are ideal locations for exploiting solar energy (SUN *et al*.,2022). However, they also present unique challenges, particularly the high levels of dust that accumulate on photovoltaic panels, leading to significant efficiency losses (KHALID *et al*.,2023). Fixed solar panels in such environments can lose between 0.4% and 0.8% of their efficiency per day due to dust deposition, with efficiency losses reaching up to 60% after dust storms (AWADH,2023). Additionally, washing photovoltaic solar panels with water in arid regions is not only impractical but also environmentally and logistically problematic, requiring extensive human intervention in remote locations where temperatures can exceed 50°C during the day (NAJEEB *et al*.,2018).

In general, photovoltaic panels are typically installed at a fixed tilt and orientation, often towards the south or north, depending on the geographic location relative to the equator. These installations are often deployed in large open spaces that lack infrastructure for regular maintenance, making frequent cleaning difficult. An automatic cleaning robot for solar panels offers a promising solution to overcome these challenges, ensuring optimal panel cleanliness without the need for constant manual intervention (ZHAO *et al*., 2022). Furthermore, to absorb the maximum solar energy around noon, when the sun is at its zenith and solar radiation is at its peak, the panels must be appropriately oriented (EBHOTA, 2022).

In addition to cleanliness, the efficiency of photovoltaic panels can be improved through optimal positioning (STANKOVIC *et al*.,2023). Typically, panels are oriented based on a pre-calculated optimal angle for the specific site. However, such fixed orientation limits energy capture during the early and late hours of the day (VISHAL.M. JOSHI *et al*., 2022). This limitation can be mitigated by employing a sun tracking system that continuously adjusts the panel's position to minimize the angle of incidence between the incoming solar rays and the panel surface (WEI *et al*.,2023). Sun tracking, combined with automated dust cleaning, has the potential to significantly enhance energy yield, particularly in challenging environments like deserts (VISHAL.M. JOSHI. *et al*.,2022).

From an economic standpoint, sun tracking and self-cleaning systems need to justify their additional costs, including those related to motors, control circuits, and maintenance (Alam *et al*.). These systems are only advantageous if the incremental costs are outweighed by the increase in energy production compared to a fixed system (CHOGUEUR.D *et al*., 2015). This research focuses on designing an integrated system that combines sun tracking and autocleaning mechanisms to maximize photovoltaic efficiency (GREENSTEIN and HUTCHISON, 2022). By addressing the challenges of optimal sunlight exposure and dust accumulation, this study aims to provide a viable solution for improving solar energy yield, particularly in harsh, dusty environments.

This research contributes to exploiting the extremal control theory to realize a solar tracking system by exploring new ways to maximize the solar radiation incidents on photovoltaic panels (LOUZAZNI, M., *et al*., 2014). The incorporation of an automatic cleaning system exploits theoretical aspects to maintain the optimal efficiency of the panels by mitigating the effects of dust accumulation. Although the impact of dirt on the performance of photovoltaic panels is recognized, the development of automated cleaning solutions exploits the theoretical framework of photovoltaic system maintenance. The integration of an automated cleaning system exploits theoretical aspects to maintain optimal panel efficiency by mitigating the effects of dust accumulation. Although the impact of dust on the performance of photovoltaic panels has been recognized, the development of automated cleaning solutions improves the theoretical framework for the maintenance of photovoltaic systems (MONTO, M., ROHIT, P. 2010).

The objective of this article is to design, implement, and evaluate an integrated sun-tracking and autocleaning system for photovoltaic panels, demonstrating its technical feasibility, and potential to significantly enhance energy production in challenging environments.

2 BACKGROUND AND MOTIVATION

Several studies have been carried out, notably on dirt-resistant photovoltaic modules (NAJMI and RACHID, 2023). In addition, oscillating water columns, air pulses, ultrasonic vibrations, mechanical windscreen wipers and waterless electrodynamic systems have been proposed (OPOKU *et al*., 2023). However, with the sudden increase in the number of solar panels installed, the construction and maintenance of solar panel cleaning and maintenance systems has put a strain on water resources (MUKASIR *et al*., 2023). In addition, photovoltaic modules often operate in difficult climates, far from urban centers, and cleaning requires high transport costs for water and labor. To solve these problems, systems such as autonomous and semi-autonomous solar-powered robots have been proposed (VISHAL.M. JOSHI *et al*, 2022). However, for on-site cleaning, particularly in deserts and semi-deserts, the deployment of large wireless robots requires a large amount of communication equipment, which is expensive and inefficient in the case of solar energy.

3 SUN TRACKING SYSTEMS

Sun tracking systems can be categorized into single-axis and dual-axis designs. Single-axis trackers follow the sun’s movement from east to west, while dual-axis systems also adjust for seasonal variations in solar declination (SAMANIEGO *et al*., 2019). Previous studies indicate an increase in power generation by up to 30-40% with the implementation of dual axis tracking systems

(ALOMAR *et al*., 2023). Dual-axis tracking systems provide better results in regions with significant seasonal variations, while single-axis trackers offer a more cost-effective solution for areas with less variability. However, the complexity and energy consumption of tracking mechanisms remain a significant engineering challenge (GYIMAH *et al*., 2022).

4 SELF-CLEANING MECHANISMS

The proposed autocleaning mechanism combines these methods to create a cost-effective and efficient solution for maintaining panel cleanliness, leveraging a hybrid approach to balance cost, effectiveness, and reliability (KIM *et al*., 2023). To address these challenges, recent advances have explored the use of AI algorithms to optimize sun-tracking movements, minimizing energy usage while ensuring optimal positioning (HALL and ELLIS, 2023). Additionally, lightweight materials and efficient motor technologies are being investigated to reduce the overall weight and power needs of tracking systems (LIU *et al*., 2017).

Recent innovations have introduced electrostatic-based cleaning methods that do not require water, making them particularly suitable for arid regions (MOKHTAR and SHAABAN, 2022). Additionally, self-cleaning systems that use vibration mechanisms are being explored to dislodge dust without the need for brushes or water, thereby reducing wear and maintenance costs.

5 SOLAR TRACKING SYSTEM OPERATION

Once the tracker aligns itself initially with the sun, it continuously seeks the optimal position by sending signals to the panel drive system, which then adjusts the orientation accordingly to track the sun throughout the day. Initially, the tracker measures the light intensity at its current position and then moves left until it surpasses a predefined angular value of α. Upon reaching this threshold, the system changes direction and moves to the right, exceeding the position to a value of -α. This oscillating movement continues in a loop to find the most effective angle for sunlight capture. If the light intensity values are found to be equal on both sides, the tracker resets to the center position and pauses briefly before reevaluating.

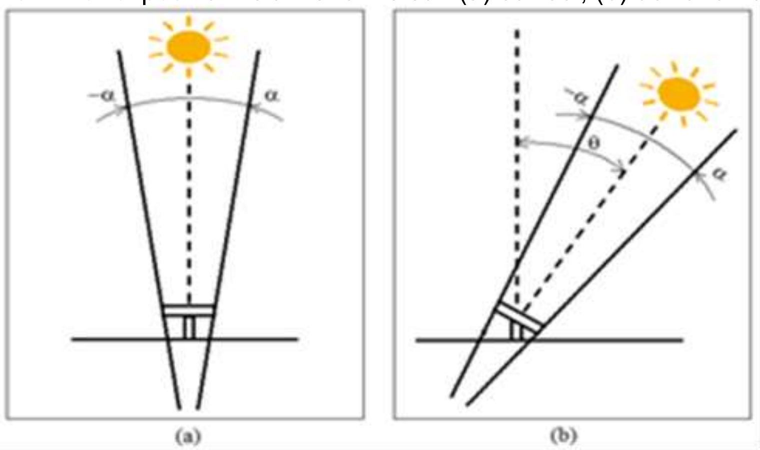
The tracker waits for four minutes (since the sun shifts one degree every four minutes) before rechecking positions. Once the tracker reaches a 180-degree movement (equivalent to nine hours), it returns to its initial starting point and enters sleep mode.

The panel position correction actuators are activated whenever the angular deviation θ exceeds the set threshold θ_C. The system operates as follows:

a) When the orientation is correct, the sensor oscillates on either side of the sun's position to maintain alignment.

b) As the sun continues its westward movement, the panel and sensor gradually form an angle θ. When θ reaches the critical value θ_C, the control circuit activates the drive motor, which reorients the panel to minimize this deviation.

Figure 1. Panel position relative to the sun (a) correct, (b) deviation of θ°.



Source: Authors.

6 CLEANING SYSTEM OPERATION

The automatic solar panel cleaning system integrates several components like dusty sensor, DC Motors and windshield wiper to ensure efficient cleaning of the solar panels.

A Real-Time Clock (RTC) module is configured to automatically start the cleaning process at 6:00 AM every 24 hours, thus ensuring routine maintenance in automatic mode.

To operate the cleaning mechanism, the same L293D motor driver from the solar tracking system is used to control the movement of a cleaning system DC motor.

Limit switches are placed at both ends of the wiper path to stop the motor at the appropriate points. When the wiper touches one limit switch during clockwise movement, the motor stops. Reverse movement to the other limit switch activates the wiper.

The system is set to clean the solar panel every day at 6:00 AM, with the wiper moving clockwise twice before reversing. After completing its clockwise sweep and reaching the limit switch, the system stops for one minute and then moves counterclockwise. The entire system thus ensures that the solar panels remain clean, improving their efficiency.

7 SIMULATION AND ROUTING

The circuit that controls the system consists of several interconnected components designed to efficiently automate the solar tracking and automated solar panel cleaning functions.

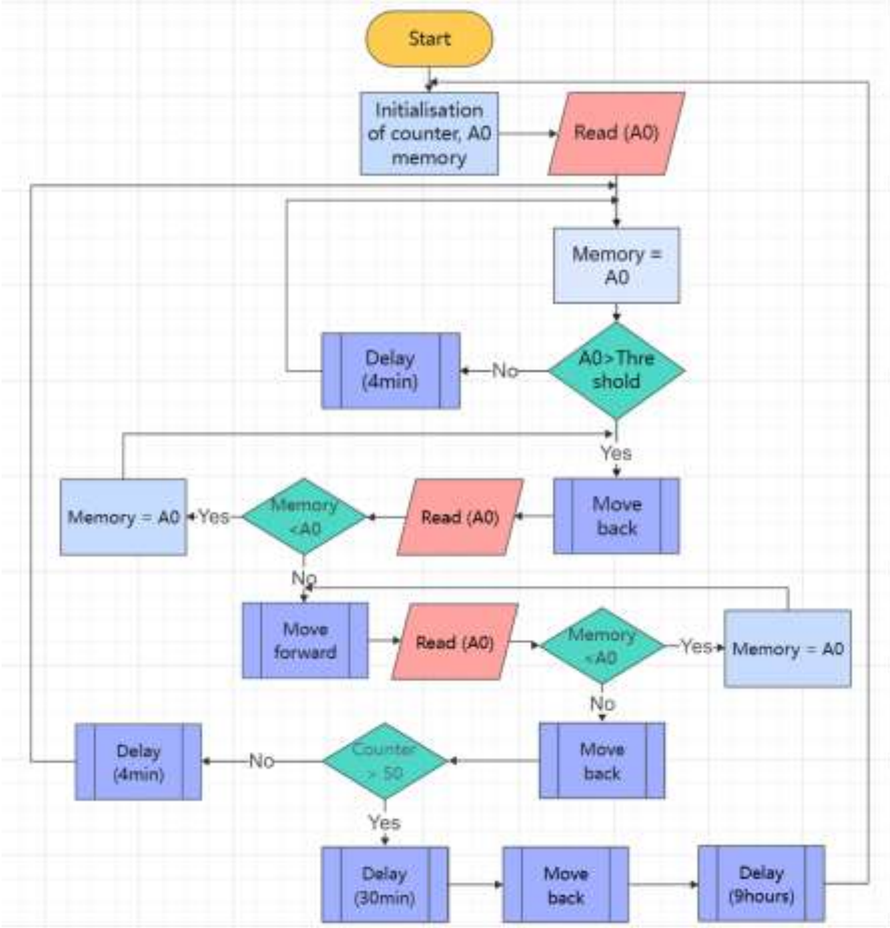
The main goal of the system is to precisely orient the photovoltaic panel towards the sun to maximize energy absorption and automate the cleaning process whenever the panel surface becomes dusty.

The solar cell, connected to the Arduino Uno's analog input A0, continuously measures the solar intensity and acts as a solar sensor. By providing real-time data on sunlight levels, this cell helps the Arduino Uno calculate the optimal angle for the photovoltaic panel. Based on this information, the Arduino Uno sends signals to a linear actuator, which adjusts the orientation of the photovoltaic panel, ensuring that it remains facing the sun throughout the day.

The photovoltaic panel acts as the main power source for the system. It generates the power needed to power the Arduino Uno, the linear motor, and two DC motors to operate the windshield wiper for cleaning. When the dust sensor detects that the surface of the panel is dirty, it sends a signal to the Arduino Uno. The Arduino then activates the L293D, which powers two DC motors. These motors drive the windshield wiper, cleaning the panel surface to ensure optimal performance. In general, this system tracks the sun independently to optimize energy capture and cleans itself whenever dust buildup is detected, ensuring consistent and efficient operation.

The flowchart of the Arduino uno code for the solar tracking system is shown in Figure 2, and the one for the cleaning system is shown in Figure 3.

Figure 2. The flow diagram of Arduino uno code for solar tracking system.



Source: Authors.

Figure 3. The flow diagram of Arduino uno code for PV cleaning system.

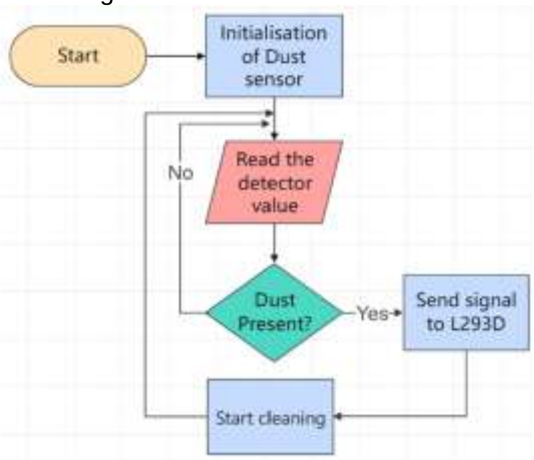


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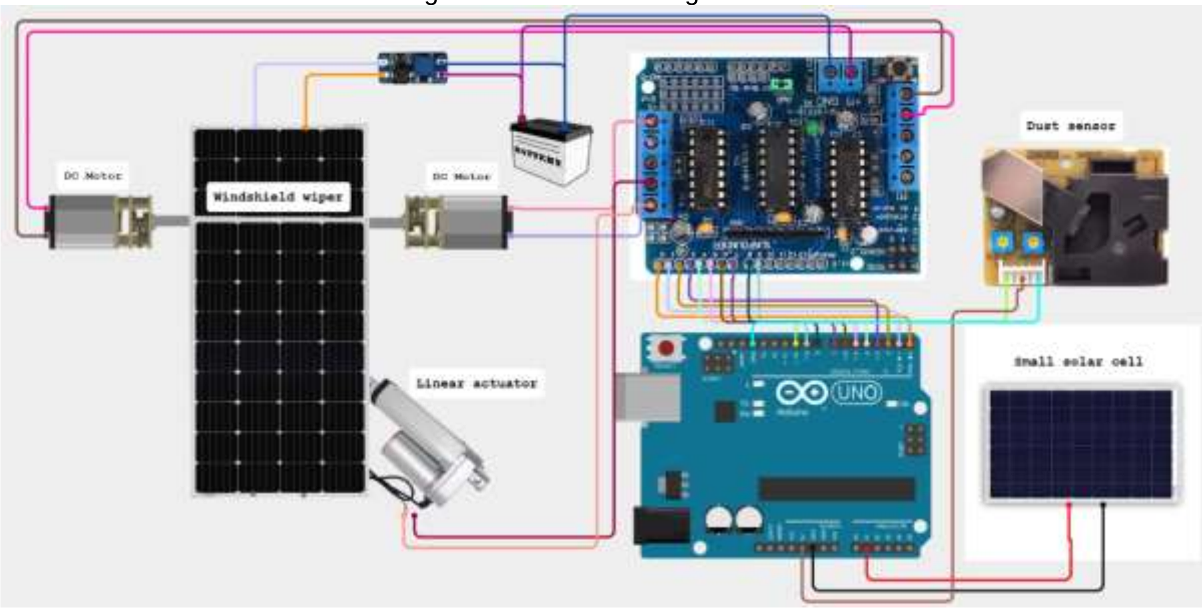
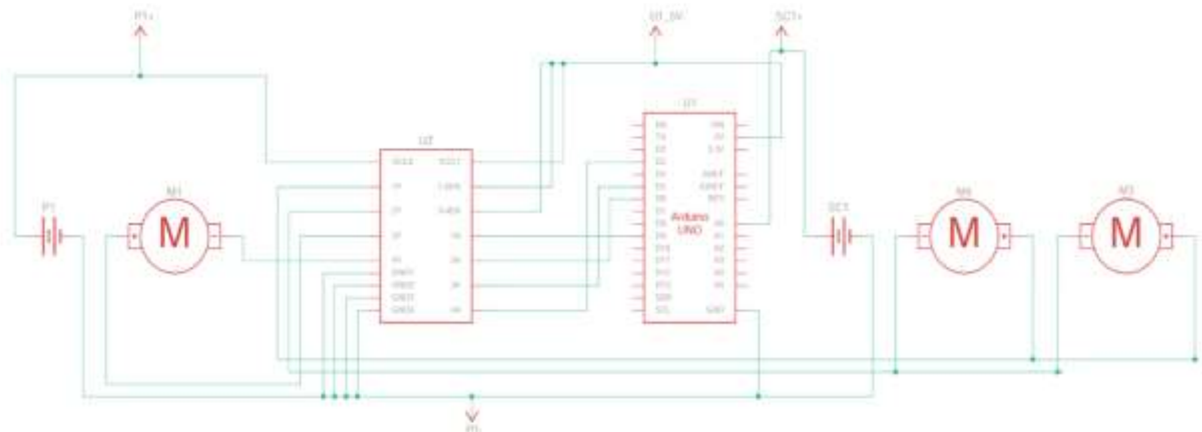
Figure 4 provides a circuit diagram of the project while Figure 5 provides a complete electronic schematic of the system.

Figure 4. The circuit Diagram.



Source: Authors.

Figure 5. Electronic diagram of the system.



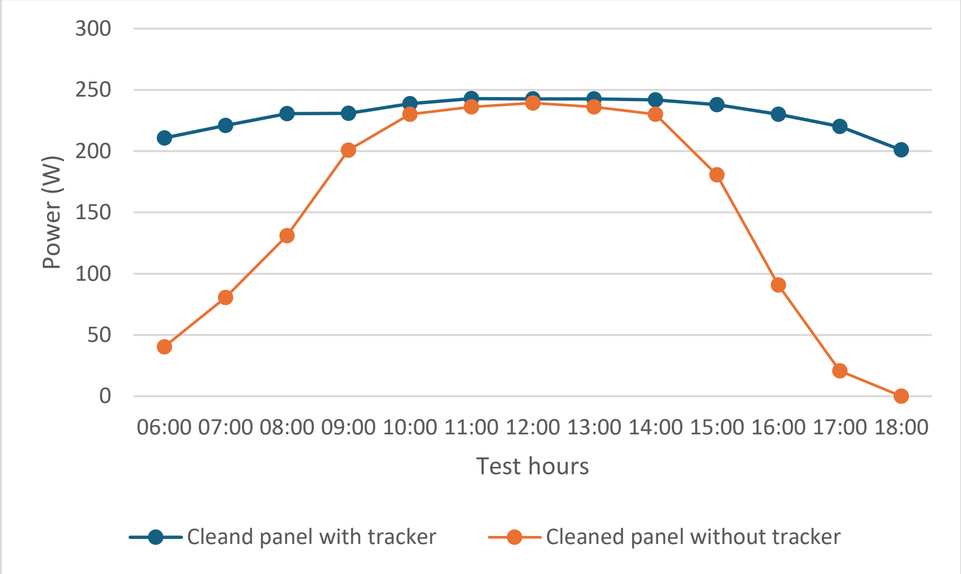
Source: Authors.

8 EXPERIMENTAL RESULTS

The following graphs show the test results of the sun-tracking system and the automatic cleaning of the solar panels.

Figure 6 shows that with a 250-watt solar panel, the power produced by the sun-tracking system is almost constant from sunrise to sunset, in contrast to the output of a fixed panel, which only reaches maximum power between 11 and 13 o'clock.

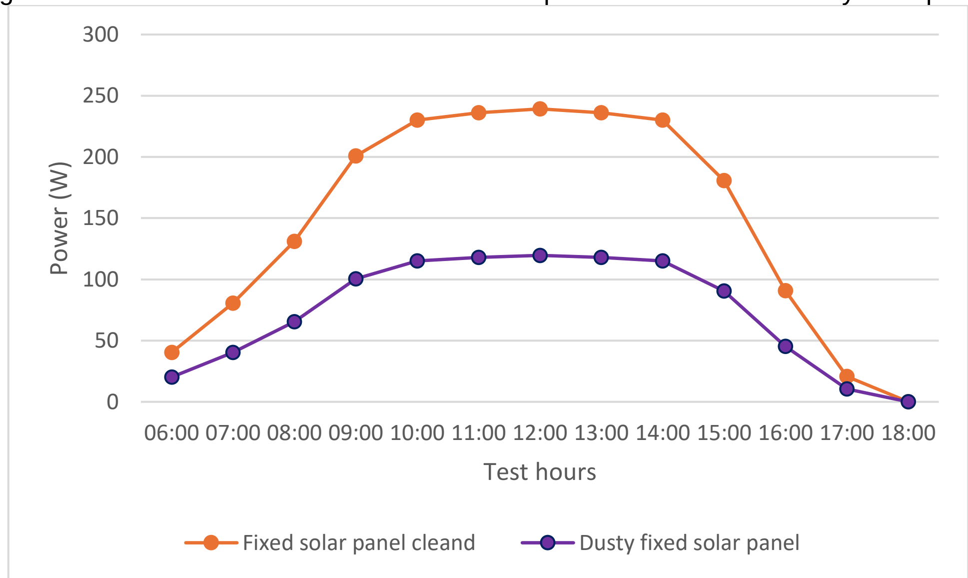
Figure 6. Power characteristics between a fixed panel and a panel with the tracker.



Source: Authors.

Figure 7 shows the difference in power output between a cleaned fixed solar panel and a dusty fixed panel, where the solar panel loses around 54% of its capacity due to dust.

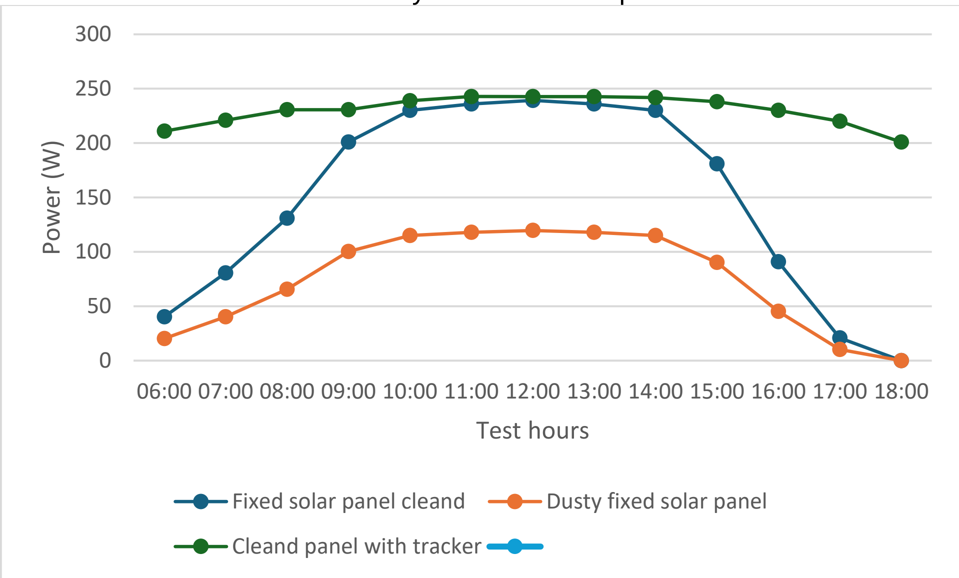
Figure 7. Power characteristics between a fixed panel cleaned and a dusty fixed panel.



Source: Authors.

Figure 8 shows the difference between the power produced by two panels, one fixed and one dusty, and a moved panel automatically cleaned.

Figure 8. Power characteristics between a cleaned fixed panel, a dusty fixed panel and an automatically cleaned mobile panel.



Source: Authors.

Our observations and analysis have shown that our solar tracking system and automatic solar panel cleaning significantly increase energy production.

9 CONCLUSION

This paper presents a novel and straightforward control implementation of a solar tracker that uses a single-axis linear actuator to follow the sun, coupled with a self-contained small solar cell to accurately determine the sun's orientation and a sensor to perform the cleaning process via two DC motors and a windscreen wiper. The proposed design, which relies on a pre-programmed Arduino Uno card for automatic orientation and cleaning, is uncomplicated and self-sufficient, eliminating the computer interface.

A prototype was successfully built and tested to verify the effectiveness of the control system. Experimental results showed that the developed system enhanced energy gain on partly cloudy days. Two algorithms were developed: One for cleaning the panel and the other for tracking the sun. The self-cleaning and tracking mechanism was successfully implemented, with different test cases leading to clear conclusions.

The results indicate that tracking outperforms fixed systems, but only when the board is cleaned of dust. Implementing the tracking system without cleaning leads to an efficiency that is lower than that of the cleaned fixed panel. In addition, the efficiency of the tracker can drop by 54% without cleaning. As shown in Figure 8, the efficiency of the board improves when both tracking and cleaning systems are used.

Experimental results have shown a significant increase in energy efficiency, confirming that integrating our prototype improves the overall performance of photovoltaic installations.

In societal terms, these results are helping to facilitate the adoption of solar technologies by improving the efficiency and reliability of photovoltaic systems. Improved energy efficiency reduces dependence on non-renewable energy sources, thereby promoting the transition to clean, sustainable energy. For the academic world, this research opens up new perspectives in the optimization of solar energy systems, encouraging the development of innovative solutions to today's energy challenges.

Despite the promising results, this study has certain limitations. The prototype developed was tested under controlled conditions, and it would be necessary to evaluate its long-term performance in a variety of environments to ensure its reliability and durability. In addition, the detailed economic analysis of integrating this system has not been fully explored; an in-depth cost-benefit study would be beneficial to determine the commercial viability of the proposed solution.

For future research, it is recommended that the use of intelligent materials and advanced sensor technologies be explored to further improve the efficiency of the system. The study of environmental impact could also be an important focus.

REFERENCES

ALAM, MD. SHAFIUL, *et al*. **Solar and Wind Energy Integrated System Frequency Control: A Critical Review of Recent Developments**. Energies, 2023.

ALOMAR, O., ALI, O. M., ALI, B. M., QADER, V. **Energy, exergy, economic and environmental analysis of photovoltaic solar panel for fixed, single and dual axis tracking systems: An experimental and theoretical study**. Case Studies in Thermal Engineering, 2023.

AWADH, SALIH MUHAMMAD. **Impact of North African Sand and Dust Storms on the Middle East Using Iraq as an Example: Causes, Sources, and Mitigation**. Atmosphere, 2023.

CHOGUEUR, D., BENTOUBA, S. AND MEROUANE, A. **Smart Sun Tracking System.** 3rd International Renewable and Sustainable Energy Conference (IRSEC), 2015.

EBHOTA, W. **Impact of Photovoltaic Panel Orientation and Elevation Operating Temperature on Solar Photovoltaic System Performance**. International Journal of Renewable Energy Development, 2022.

GIELEN, D., BOSHELL, F., SAYGIN, D., BAZILIAN, M., WAGNER, N., & GORINI, R. **The role of renewable energy in global energy transformation**. Energy Strategy Reviews, Volume 24, Pages 38-50,2019,

GREENSTEIN, BRIANNA L, & G. HUTCHISON. **Organic Photovoltaic Efficiency Predictor: Data-Driven Models for Non-Fullerene Acceptor Organic Solar Cells**. The journal of physical chemistry letters, 2022.

GYIMAH, J., YAO, X., TACHEGA, M., HAYFORD, I. S., & OPOKU-MENSAH, E. **Renewable energy consumption and economic growth: New evidence from Ghana**. Energy,2022.

HALL, P., ELLIS, D. **A systematic review of socio-technical gender bias in AI algorithms**. Online Inf. Rev., vol. 47, pp. 1264-1279, 2023.

HOU, H., LU, W., LIU, B., HASSANEIN, Z., MAHMOOD, H., & KHALID, S. **Exploring the Role of Fossil Fuels and Renewable Energy in Determining Environmental Sustainability: Evidence from OECD Countries**. Sustainability 2023.

KASSEM, Y., GOKÇEKUŞ, H., HAMAD, O. A. M., & FAYID, F. M. B. **Economic Viability of a 6.5kW Off-grid Solar PV with Various Sun-Tracking Systems in Northern Cyprus: A Case Study**. Engineering, Technology & Applied Science Research, 2023.

KHALID, HARIS M., *et al*. **Dust accumulation and aggregation on PV panels: An integrated survey on impacts, mathematical models, cleaning**

mechanisms, and possible sustainable solutions. Solar Energy, 2023.

KIM, SUNGCHUL, *et al*. **Assessment of the Technical and Economic Performance of a Window-Integrated PV System Using Third-Generation PV Panels**. SSRN Electronic Journal, 2023.

LIU, REN, *et al*. **Research on High-efficient Remanufacturing Technologies and Application of Electric Motor**. IOP Conference Series: Materials Science and Engineering, vol. 231, 2017.

LOUZAZNI, M., AROUDAM, E., & YATIMI, H. **Modeling and simulation of a solar power source at 3kW for a clean energy without pollution**. MATEC Web of Conferences, 1103019, 2014.

MOKHTAR, M., SHAABAN, M. **A New ANN-Based Cleaning Approach for Photovoltaic Solar Panels**. 9th International Conference on Electrical and Electronics Engineering (ICEEE), pp. 260-263, 2022.

MONTO, M., ROHIT, P. **Impact of dust on solar photovoltaic (PV) performance: Research status, challenges and recommendations**. Renewable and Sustainable Energy Reviews. Centre for Sustainable Technologies, Bangalore 560012, India. 2010.

MOUHIB, E., MICHELI, L., ALMONACID, F., & FERNÁNDEZ, E. **Overview of The Fundamentals and applications of bifacial Photovoltaic Technology: Agrivoltaics and Aquavoltaics**. Energies, 2022.

MUKASIR, HARIS, FAIZAL ARYA SAMMAN, A., ACHMAD, & MAYA ITASARI. **Predictive Maintenance System Using Support Vector Machine Algorithm for Dust Cleaning on Solar Panels**. International Conference on Modeling & E-Information Research, Artificial Learning and Digital Applications (ICMERALDA), pp. 50-55, 2023.

NAJEEB, NITHIN SHA, P. K. SOORI, AND T. KUMAR. **A Low-Cost and Energy-Efficient Smart Dust Cleaning Technique for Solar Panel System**. International Conference on Smart Grid and Clean Energy Technologies, pp. 125-129, 2018.

NAJMI, NOUHAILA, & A. RACHID. **A Review on Solar Panel Cleaning Systems and Techniques**. Energies, 2023.

OPOKU, F., UDDIN, M. N., & ATKINSON, M. **A review of computational methods for studying oscillating water columns – the Navier-Stokes based equation approach**. Renewable and Sustainable Energy Reviews, 2023.

RASHID, F., AL-OBAIDI, M., DULAIMI, A., BAHLOL, H., & HASAN, A. **Recent Advances, Development, and Impact of Using Phase Change Materials as Thermal Energy Storage in Different Solar Energy Systems**. A Review, 2023.

SAMANIEGO, L., BRUCAL, S. G. E., CANDAVA, S. P., MENDOZA, Q. R. C., &

NASARA, R. F. V. **NI LabVIEW-Based Solar Power Recording Device for Optimizing PV Modules with Fixed Orientation and Tilt to Capture Maximum Solar Irradiance with Respect to Magnetic Declination**. IEEE 8th Global Conference on Consumer Electronics (GCCE), 1040-1044, 2019.

STANKOVIC, S., DOBRILOVIĆ, M., & ŠKRLEC, V. **Optimal Positioning of Vibration Monitoring Instruments and their Impact on Blast-Induced Seismic Influence Results**. Archives of Mining Sciences, 2023.

SUN, XIAODONG, *et al*. **Solar Energy Catalysis**. Angewandte Chemie (International Ed. in English), vol. 61, 2022.

VISHAL.M. JOSHI., SHAMRAO CHAVHAN, R. *et al*. **Sun Tracking Solar Panel with Auto Dust Cleaning System**. International Journal of Innovative Research in Science Engineering and Technology, 2022.

WEI, Y., OU, B., WANG, J., YANG, L., LUO, Z., JAIN, S. P., & HUANG, L. **Simulation of a floating solar farm in waves with a novel sun-tracking system**. IOP Conference Series: Materials Science and Engineering, 2023.

ZHAO, QING-PENG, *et al*. **Design of an automatic cleaning robot for land-based factory aquaculture ponds**. Proceedings of the 4th International Conference on Robotics, Intelligent Control and Artificial Intelligence, 2022.