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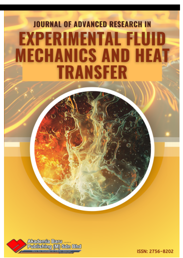

Design and Implementation of a Smart Solar Tracker using Arduino for Enhanced Energy Efficiency

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ABSTRACT

In the universe of solar energy systems, the quest for enhanced energy efficiency has led to the design and implementation of a Smart Solar Tracker using Arduino. This innovative solution leverages advanced control mechanisms to optimize solar panel orientation dynamically, addressing the inherent challenges posed by varying climatic conditions. Traditionally, solar trackers have faced limitations in adapting to changing weather patterns, impacting energy capture efficiency. The Smart Solar Tracker, outlined in this study, overcomes these challenges by integrating Arduino-based technology, demonstrating a robust and strong approach to solar tracking. The main result presented in this work showcases the superior performance of the Smart Solar Tracker, consistently delivering high and stable voltage outputs even in adverse weather conditions. Shows that the implementation of Arduino-based control systems in solar tracking significantly enhances energy efficiency, ensuring consistent power generation across diverse climatic scenarios. This advancement not only underscores the critical role of technology in optimizing renewable energy systems but also positions the Smart Solar Tracker as a promising solution for reliable and resilient solar energy harvesting. In terms of costing smart solar tracker is 3 times higher compared to traditional solar tracker whereas in terms of efficiency smart solar tracker using Arduino is 10 times which is 100 percentage more efficient compared to traditional solar tracker. The smart solar tracker using Arduino efficiency output was 68% which is the highest compared to both solar tracker which is 5% and 27% over 5 days of reading the Smart Solar Tracker. Comparison shows that the smart solar tracker using Arduino is the most efficient. The findings presented specifically lead the way for the broader integration of advanced control mechanisms in renewable energy infrastructure, fostering sustainability in the face of environmental variability.

Keywords:
Solar; Arduino; voltage; comparison;
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1. Introduction

In the global endeavor to transition towards sustainable energy solutions, solar power has emerged as one of the most promising and accessible alternatives [1]. As a clean and renewable energy source, it offers a viable path to reducing reliance on fossil fuels, mitigating greenhouse gas emissions, and addressing the urgent challenges of climate change [2]. Despite its immense potential, harnessing solar energy efficiently remains a critical challenge. Solar photovoltaic (PV) panels, the cornerstone of solar energy systems, are inherently reliant on their ability to capture sunlight. However, their efficiency is often constrained by static designs that fail to account for the sun's

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dynamic movement across the sky throughout the day and across seasons with moisture effect especially in climate region [3]. Traditional fixed solar installations, though effective, often fall short of maximizing energy production due to the dynamic nature of the sun's position in the sky [4]. The fundamental principle of solar energy optimization lies in maximizing the incident sunlight on the solar panel surface. Fixed solar installations, while cost-effective and simple to implement, are suboptimal in this regard. They are oriented to a single position and cannot adapt to the sun’s changing trajectory, resulting in significant energy losses during off-peak sun hours. This inefficiency has spurred research and development into dynamic systems that can actively track the sun's position, ensuring maximum exposure and energy conversion. Among these solutions, solar tracking systems have emerged as a transformative technology, capable of enhancing the efficiency of solar panels by up to 40% compared to fixed systems.

Numerous researchers and engineers have studied photovoltaic systems to enhance their ability to capture greater amounts of solar energy. Strategies for improving photovoltaic system efficiency can be categorized into three key approaches. The first involves optimizing the power output efficiency of solar cells, the second focuses on refining energy conversion control algorithms [5], and the third employs tracking systems to maximize solar energy capture [6]. There are also researchers who use three strategies to improve photovoltaic system efficiency [7,8]. Sun-tracking systems are categorized into single-axis [9] and dual-axis trackers based on their mode of rotation [10]. Additionally, they can be classified as active or passive trackers depending on the type of actuator used [11]. Research findings indicate that dual-axis tracking systems, which track both azimuth and altitude, are more efficient at capturing solar energy compared to fixed-panel systems [12]. However, single-axis trackers are more cost-effective and offer greater flexibility compared to their dual-axis counterparts and single-axis tracking systems are expected to be somewhat less efficient than their two-axis counterparts [13].

To address the limitations of static systems, this research proposes the development and implementation of a solar tracking system. At its core, the proposed system leverages the Arduino platform, an open-source microcontroller renowned for its versatility, affordability, and ease of integration with a wide range of sensors and actuators [14]. By employing real-time data inputs, such as sunlight intensity and directional positioning, the system enables precise control over panel movement, thereby maximizing energy capture. These enhancements make the system particularly suited for deployment in regions with varying climatic conditions, where adaptability is crucial to ensuring consistent energy output. The significance of this research lies in its holistic approach to improving solar energy systems. By integrating hardware, software, and data-driven optimization, the Smart Solar Tracker represents a comprehensive solution that addresses both the technical and economic challenges of solar tracking. Arduino’s compatibility with a wide array of components enables scalability, making the system applicable to a range of installations, from small residential setups to large-scale commercial solar farms. This paper aims to provide an in-depth exploration of the design, development, and deployment of the Smart Solar Tracker. The subsequent sections will outline the theoretical principles underpinning solar tracking, including the movement of celestial bodies and the mechanics of solar tracking systems. Furthermore, the methodology and design process will be discussed, highlighting the integration of sensors, motors, and control algorithms. Lastly, a detailed evaluation of the system’s performance will demonstrate its potential to significantly enhance the efficiency and reliability of solar energy generation. By addressing the current inefficiencies in solar tracking technologies, this research contributes to the broader goal of advancing renewable energy systems, paving the way for a sustainable and energy-secure future.

2. Methodology

The methodology employed in the design and implementation of the Smart Solar Tracker using Arduino for enhanced energy efficiency followed a systematic approach as illustrated in Figure 1. A thorough literature review was conducted to understand existing solar tracking systems and Arduino applications in renewable energy. The research design, adopting an experimental approach, set clear objectives and research questions. The system architecture was carefully crafted, delineating the interaction between components such as sensors, Arduino microcontroller, actuators, and power supply, with established communication protocols. The selection and integration of sensors involved a meticulous process, with a focus on choosing a light sensor that balanced accuracy, response time, and cost-effectiveness. Servo motors were chosen as actuators for their precision, seamlessly integrated to control solar panel orientation based on sensor inputs. Arduino programming, facilitated through the Arduino IDE, included the development of control logic for interpreting sensor data and executing precise movements. The hardware implementation comprised designing a robust physical structure, assembling components, and ensuring proper connectivity. The experimental setup is demonstrated as Figure 2. Rigorous testing, from unit tests to integrated assessments, was conducted to validate system performance, with subsequent experimentation in a controlled environment to collect data on energy output under varying conditions. Data analysis aimed to quantify the energy efficiency improvement achieved by the Smart Solar Tracker.

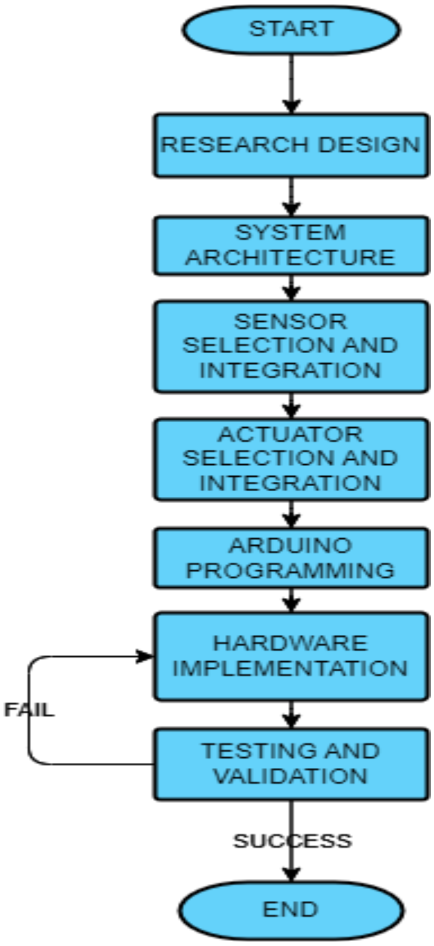

Fig. 1. Flow chart 1

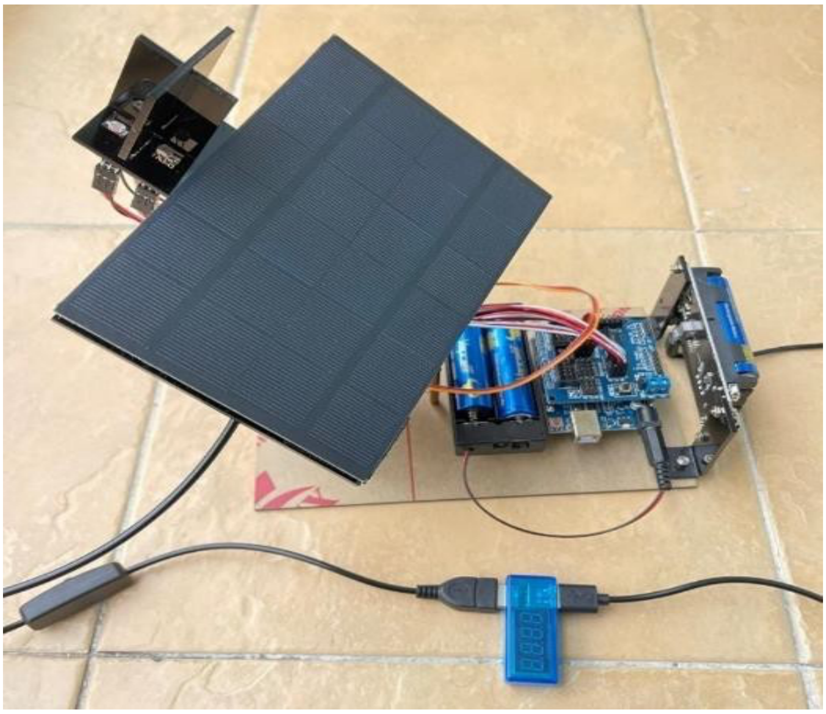

Fig. 2. Smart solar tracker experimental setup

The system for this project was demonstrated in Figure 3. The following materials were used for the development of a smart solar tracker.

- Solar Photovoltaic (PV) Panel.
- Arduino UNO Board.
- Dc (Direct Current) Servo Motor.
- Light Dependent Resistor (LDR)
- Analog-Digital-Converter (ADC)
- Resistors.
- Connecting Wires

The automatic solar tracking system is composed of several key components, including Light Dependent Resistors (LDRs), an Arduino Uno board, a Liquid Crystal Display (LCD), DC motors, a stepper motor with its driver, a solar panel, and a supporting metallic motor bracket. This electromechanical system integrates two motor drivers: a stepper motor for movement along the north-south axis and a DC motor for movement along the east-west axis. The solar panel generates a voltage proportional to the sunlight intensity, while the LDRs detect misalignment by measuring light intensity differences. These sensors send signals to the microcontroller, which processes the data and adjusts the motors automatically to realign the solar panel for optimal positioning. Due to their photoconductive properties, LDRs exhibit varying resistance values depending on the intensity of incident light. Each LDR transmits a signal corresponding to its resistance to the microcontroller, which, using programmed logic, compares these values relative to a reference LDR.

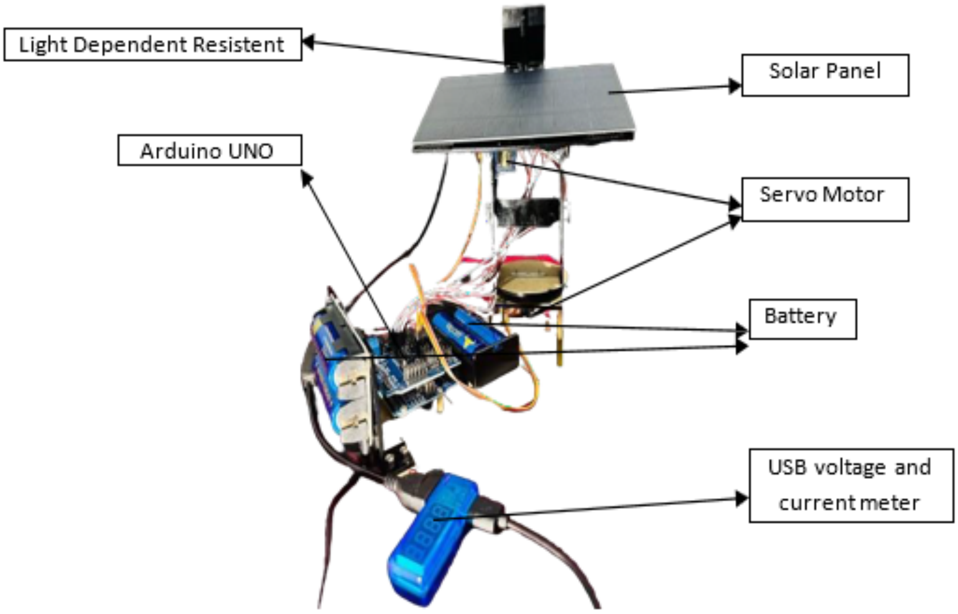

Fig. 3. Illustrate component of smart solar tracker using Arduino

The system is designed with one DC motor mechanically linked to the driving axle of another DC motor. This arrangement allows the first motor to rotate in conjunction with the axle of the second, enabling the solar panel to move along both the X-axis and Y-axis as illustrated in Figure 4. The microcontroller sends precise signals to the motors based on the inputs from the LDRs, enabling dual-axis tracking. One DC motor manages adjustments along the X-axis, while the second handles movement along the Y-axis, ensuring that the solar panel maintains optimal alignment with the sun's position.

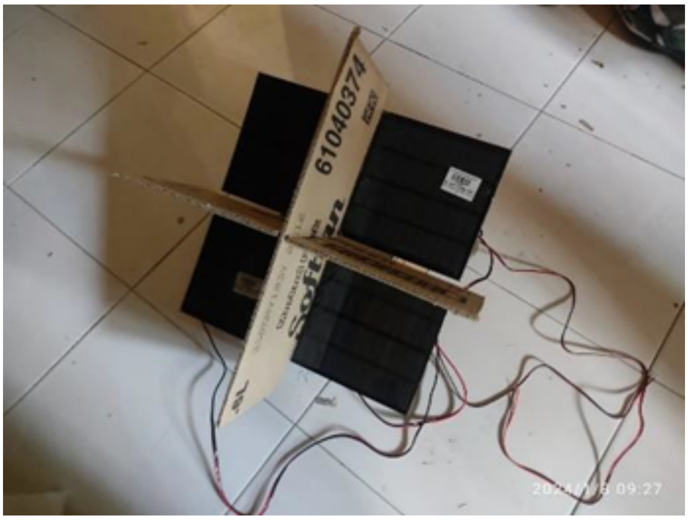

Fig. 4. Low-cost solar tracker using shadow detection experimental setup

3. Results and Discussion

The study conducted a comparative analysis of three distinct solar tracker types which is the traditional solar tracker, a low-cost solar tracker using shadow detection, and the proposed Smart

Solar Tracker using Arduino technology. The investigation was conducted in a five day period, from December 15 to December 19, 2023, capturing data at 15-minute intervals between 9 AM and 6 PM each day. The average voltage over 5 days is presented in Figure 5. This timeframe allowed for a comprehensive examination of the trackers' performance under varying sunlight conditions.

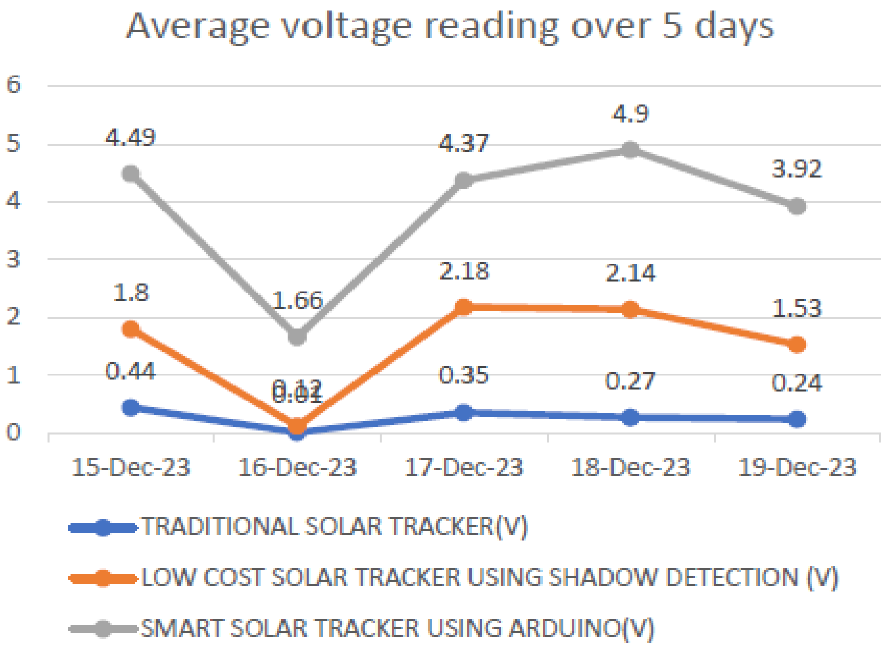

Fig. 5. Comparison graph of 5 days

The examination of average voltage readings spanning five days, encompassing diverse weather conditions of sunny day, cloudy day, and rainy day reveals intriguing engineering insights into the performance of three distinct solar trackers. The Traditional Solar Tracker consistently exhibited the lowest average voltage readings, ranging from 0.24 V to 0.44 V across the five days. This trend underscores its limited efficiency in harnessing solar energy, as it struggled to adapt to varying sunlight intensities and weather conditions [15]. The conventional tracker's performance variability, even under different climatic conditions, indicates its inherent limitations in maximizing energy capture [16]. In contrast, the Low-Cost Solar Tracker using Shadow Detection demonstrated an intermediate performance with average voltage readings ranging from 0.12 V to 2.18 V. The wider range of values suggests its ability to adapt to changing sunlight conditions through shadow detection mechanisms. However, the tracker exhibited sensitivity to weather fluctuations, with voltage outputs fluctuating more noticeably during cloudy and rainy days. This adaptability, while commendable, implies a degree of vulnerability to environmental factors. The standout performer was the Smart Solar Tracker using Arduino, consistently yielding higher and more stable average voltage readings between 1.66 V and 4.90 V. In term of costing smart solar tracker is 3 times higher compared to traditional solar tracker whereas in terms of efficiency smart solar tracker using Arduino is 10 times which is 100 percentage more efficient compared to traditional solar tracker. The smart solar tracker using Arduino efficiency output was 68% which is the highest compared to both solar tracker which is 5% and 27% over 5 days of reading the Smart Solar Tracker as shows in Figure 6. The advanced control mechanisms of the Arduino-based system demonstrated remarkable efficiency in optimizing solar tracking, even a midst varying climatic conditions. Notably, the tracker showcased superior stability and resilience, maintaining relatively high voltage outputs even on cloudy and rainy days. This resilience is a significant advantage, ensuring continuous energy production despite adverse weather conditions, thus addressing a critical concern in solar energy systems. From an engineering standpoint, these findings underscore the critical role of advanced control systems, such as Arduino-based technology, in mitigating the impact of changing weather conditions on solar tracker performance. The ability to precisely adjust panel orientation and optimize energy capture in real-time is a significant advantage in ensuring consistent and efficient energy production. This comprehensive analysis not only highlights the importance of technological advancements in solar tracking systems but also emphasizes the need for robust designs that can operate seamlessly in diverse climatic scenarios. The Smart Solar Tracker's ability to deliver consistent and elevated voltage outputs in adverse weather conditions positions it as a promising solution for reliable and resilient solar energy harvesting systems.

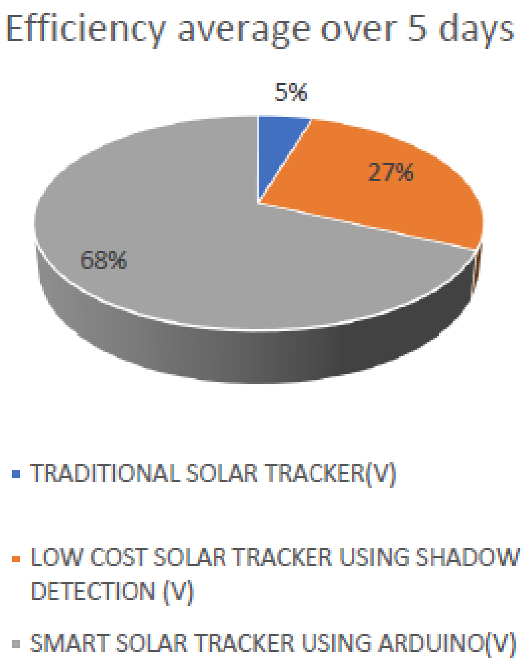

Fig. 6. Comparison efficiency over 5 days

4. Conclusions

In a nutshell, the Design and Implementation of a Smart Solar Tracker Using Arduino for Enhanced Energy Efficiency is a significant advancement in renewable energy technology. The main objective of this thesis was to understand, develop, and finally construct an intelligent solar tracking system that used Arduino microcontrollers to dynamically improve solar panel orientation. This effort was motivated by the need to overcome the limits of fixed solar systems, which frequently suffer from diminished efficiency due to insufficient sunlight exposure angles. This technology automatically modified the orientation of solar panels to correspond with the position of the sun, ensuring maximum sunlight exposure throughout the day. To evaluate the system's efficiency, reliability, and dependence on energy output, extensive testing and data collecting were carried out under a variety of environmental circumstances. The findings precisely confirm the project's primary goal of increasing energy efficiency in solar power generation. In term of costing smart solar tracker is 3 times higher compared to traditional solar tracker whereas in terms of efficiency smart solar tracker using Arduino is 10 times which is 100 percentage more efficient compared to traditional solar tracker. The smart solar tracker using Arduino efficiency output was 68% which is the highest compared to both solar tracker which is 5% and 27% over 5 days of reading the Smart Solar Tracker.

The research provides beneficial information for renewable energy researchers and practitioners by searching into issues with design, resolving implementation problems, and enhancing performance. Because the Smart Solar Tracker is a tangible result of this study, it represents the project's successful completion. This accomplishment is not limited to theoretical advances; it offers potential for real-world applications, leading the way for a future in which better energy efficiency through smart solar monitoring is an essential component of sustainable energy solutions. In conclusion, the Design and Implementation of a Smart Solar Tracker Using Arduino not only achieved its stated goals, but it also developed the way for future advancement and innovation in the growing sector of renewable energy.

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