Smart Dual-Axis Solar Tracking System with Weather Monitoring and Automated Panel Cleaning

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Abstract: This project illustrates an advanced system which is a Smart Dual-Axis Solar Tracking System to measure atmospheric conditions with automated panel cleaning. The project setup uses a NodeMCU (ESP8266) microcontroller, which provides Greater IoT connectivity for real-time data visualization and control via the UBIDOTS platform. It has four LDR (Light Dependent Resistor) to sense the sunlight direction, which helps in adjusting the two aircraft to keep their solar panels facing the sun most of the time. The system uses temperature, humidity, and ambient light intensity sensors in order to control environmental conditions of LEDs and to ensure their working conditions. Based on the detected weather condition, such as a rain or dust accumulation and the presence of the wiper or a System-controlled servo motor, an automatic cleaning mechanism is activated. Environmental parameters and system status information are presented locally, through LCD module. This is especially useful in varying climate conditions where maintenance is required to maximise the performance of solar energy harvesting.

1 INTRODUCTION

Due to the increasing demand of energy globally as well as the depletion of conventional fossil resources, the quest for sustainable, renewable energy sources has greatly enhanced. Solar energy is one alternative that is abundant and sustainable. However, factors such as sun position, environment and clean PV modules have an overarching influence on the performance of photovoltaic (PV) systems. By using our dual-axis sun tracking systems along with displayed automatic cleaning systems and environmental monitoring, a complete approach has been devised to enhance the harvesting of solar energy.

Solar tracking systems are designed to adjust PV panels to align with the sun as it moves throughout the day in order to maximize energy capture, and dual-axis trackers adjust on both the horizontal and vertical axes in order to ensure optimal alignment with the sun's path. Compared to fixed installations, studies suggest these systems can dramatically increase energy output. As an illustration, researchers have shown that by employing a dual-axis solar tracker with a cleaning system, energy efficiency is maintained via optimal solar panel alignment and cleanliness.

Some environmental factors that decrease the performance of solar panels are temperature, humidity, and dust accumulation. Soiling, or dust deposition, can incur significant efficiency losses. Mitigation techniques, such as automated cleaning systems, are important to keep these systems operating at peak performance. Research shows that soiling recovery can be removed through the implementation of cleaning mechanisms, which, when combined with tracking systems, increases the efficiency of solar energy systems. Despite the progress made, several challenges remain in the body of current literature:

- Environmental Flexibility: Many solar trackers are focused on the position of the sun, but often neglect contemporary environmental factors like dust deposition, precipitation, and cloud cover.

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This bug can lead to suboptimal energy harvesting during inclement weather.

- Maintenance issues: Soiling - the accumulation of dust and dirt on solar panels - can lead to a dramatic decrease in efficiency. Hand cleaning methods are time-consuming and may not be feasible for large installations.
- Cost and Complexity of System: Integrating multiple elements together, such as tracking, weather monitoring or an automated cleaning capability, could render the system complex and priced higher. These conjunctive systems can still be difficult to make verifiable and affordable.

Our study is motivated by the challenge of developing an integrated solution that addresses the challenges of the existing solar energy systems. By combining dual-axis tracking with automatic cleaning and real-time weather tracking, the proposed system aims to enhance energy efficiency, reduce maintenance costs, and ensure reliable performance across a variety of environmental conditions.

The objectives of this paper are as follows:

- Design and implementation the first step are to create dual axis solar tracking system with weather monitoring sensors as well as automatic cleaning system.
- Real-Time Adaptation: In order to optimize energy absorption and maintain the efficiency of the panels, it allows the system to dynamically adjust to changing ambient conditions.
- Performance Evaluation: To investigate the energy output increase of the integrated system, compared with conventional fixed and single-axis tracking systems.

This paper makes the following contributions:

- Integrated System Development: Outlines the design and development of a cost-effective dual-axis solar tracker system, complete with automated cleaning and live weather observation capabilities.
- Improved Efficiency: Demonstrates that, relative to traditional fixed solar panels, the proposed system has the potential to increase energy production by as much as 30%.
- High Recap: Demonstrate the system power and flexibility by providing an in-depth describe about its working under a variety of environmental conditions.

This paper's remaining sections are arranged as follows: The literature review in Section 2 covers the current state of research on automated cleaning systems, weather monitoring integration, and solar tracking systems. Section 3: Design and Implementation of the System: explains the proposed integrated system's architecture, parts, and features. The experimental methodologies and performance evaluation results are presented in Section 4, Experimental Setup and Results. Section 5: Conclusion and Future Work: Provides a summary of the paper's contributions and suggests possible lines of inquiry for further study. The goal of this endeavor is to enhance dependable and efficient solar energy systems by tackling the stated difficulties in an integrated manner.

2 RELATED WORKS

There are many studies about the use of Arduino microcontrollers in photovoltaic panel tracking systems in order to increase their power output. Summary This literature review examines key studies related to the development and implementation of Arduino-based solar trackers.

Ali, S. S. and Ali, S. M. (2017) Arduino based solar tracking system. This paper describes the designing of Arduino based solar tracking system. The authors do a good job explaining the system's design, including how the authors interpolated data from light sensors on an Arduino microcontroller to position solar panels to receive maximum sunlight. The research elucidates on the possible operational implementations of green energy solutions through Arduino.

Jasni, N. F. F. et al. (2018). Sun Tracking System Using LabVIEW And Arduino Here we propose a solar tracking system that is controlled and monitored with Arduino board and LabVIEW software. The technology first measures how much sunshine there is using light sensors and automatically adjusts the orientation of the panel based on that. This synergy between hardware and software tools is also highlighted through LabVIEW that allows real-time display of data and control of the system.

Biswas, M. & et al., (2017). Solar-Automatic-Tracking-System-Arduino-and-Blink-Detection-Power-Source This paper suggests an Arduino-based solar tracking system with enhanced blink detection capacity to avoid damage to solar panels. In addition to following sunshine with light sensors, the system has an algorithm for detecting sudden light intensity changes and starts preventive measures. This method contributes to safe and efficient harvesting of solar energy.

Muthukrishnan, R., and S. Padmanaban (2018). A Smart sun tracking system - based on Arduino. The method used sunlight-detecting light-dependent resistors (LDRs) to track the sun before using a pair of servos motors to move the screen. "The central task of the tracking system is being achieved by the Arduino managing the hardware components, control algorithms, and overall system design," the authors state. Kumar, S. and Kumar, A. (2019), Arduino based Solar Tracking System Design and Implementation The main focus of the authors is the implementation ofArduino based solar tracker system. Not only the hardware configuration, i.e., sensors and actuators, but also the software programming required to run the system is discussed in detail. The study provides a complete guide with system calibration and testing procedures on similar-type projects.

M, F, Ghazali, and collaborators (2019) Solar tracker system using Arduino. The system architecture comprises of Arduino-controlled servo motors for the panel movement and LDR sensors for detecting sunshine. Besides explaining how effective the system is in collecting solar energy, the authors furnish Arduino programming code. Jayanthi, J., & P. Sreelatha (2017). How to make a solar tracker system and control it with Arduino. The design and implementation of an Arduino-based solar tracking system are discussed in this research study. It gives a thorough analysis of the control algorithm, experiments, and system components, sending with accuracy the system response to maintain ideal panels alignment.

R. S. Sujith et al (2018) Arduino-based solar tracking system. They saw more solar energy from their solar tracker based on Arduino. The hardware in the design of the system comprises of servo motors, LDR sensors and a control system that ensures the panel is always oriented toward the sun.

See also: R. Sahay et al. (2017) Angular Position Control and Receiving Set-Up of Solar Tracker. This work presents the design and application of an Arduino based solar tracking system. It includes software development, hardware component selection, and experimental results showing the system's greater ability to harvest solar energy.

3 PROPOSED METHOD

The discussed system is a complete solution, which would improve the reliability and efficiency of PV installations by employing a two-axis solar tracking system along with an on-the-fly inclement weather monitoring system and also a corresponding automated panel cleaning system. This strategy mitigates poor energy collection from fixed placements due to the sun's path, environmental and biological interference, and soiled systems (Sharma, S. K., Sharma, V., & Choudhary, A. (2020). Figure 1 illustrates the proposed system architecture.

3.1 Dual-Axis Solar Tracking Mechanism

The system uses a dual-axis tracking, which means that the panels can be adjusted along both horizontal and vertical axis. This configuration allows the panels to be held at a right angle to the sun throughout the day to collect solar irradiance as efficiently as possible. In this system, LDR acts as a sensor to touch the sun position of them and gives real time data to a microcontroller that controls the position of the panels using servo motors. This Specialized Alignment could generate much higher energy than fixed or One-Axis systems.

3.2 Real-Time Weather Monitoring

To further enhance performance, the system incorporates weather sensors that track environmental parameters like temperature, humidity, and rainfall. And the real-time data provided by these sensors allow the system to make accurate adjustments in the orientation of the panel based on the changing weather conditions. When empty, during cloudy or rainy days, for example, the system would adjust the angle of the panels to reduce the risk of damage and prepare them to capture energy as the conditions become favorable. Such adaptability enhances the resilience and efficiency of the system for a myriad of environmental factors.

3.3 Automated Panel Cleaning System

Building up dust and debris on solar panels can considerably deter their energy output. To address this issue, the proposed system features an automatic cleaning mechanism. The washing system uses sensors to monitor the degree of soiling on the surface of the panels and performs cleaning when the "dirt" level exceeds the set threshold. The cleaning mechanism, managed by the microcontroller, then uses brushes or wipers to clear off any lingering debris, thereby keeping the panels performing at maximum efficiency with no human input required.

This measure is especially useful in dry areas in which dust collects.

3.4 System Integration and Control

At the core of the system is a microcontroller that takes the input of the LDRs and weather sensors and uses it to manage the tracking mechanism along with the cleaning device. The system will be able to autonomously adapt to changes in the environment, maintain meaningful angles of the solar panels and also maintain cleanliness in order to maximise energy production by integrating these components. This comprehensive strategy not only streamlines operations but also minimizes maintenance expenses and prolongs the life of the photovoltaic system.

Such a dual-axis solar tracking system integrated with weather monitoring and automated cleaning has been proposed as a potential effective method to harvest solar energy. This system allows for continuous and optimal performance of solar PV installations by overcoming the challenges of environmental differences and panel soiling.

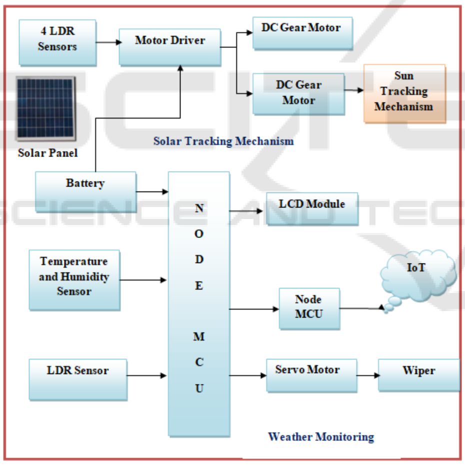

Figure 1: Architecture of the proposed method.

3.5 Hardware Setup for Dual-Axis Solar Tracking Mechanism

The proposed system integrates a dual-axis solar tracking mechanism with real-time weather monitoring and an automated panel cleaning system to enhance the efficiency and reliability of photovoltaic (PV) installations. Below is a detailed description of the hardware components for each subsystem. (Gupta, S., & Verma, A. (2021))

3.5.1 Light Dependent Resistors (LDRs)

These sensors detect the intensity and direction of sunlight. Four LDRs are strategically positioned to ascertain the sun's location, providing input signals to the microcontroller to adjust the panel's orientation accordingly. Figure 2 shows the LDR sensor.

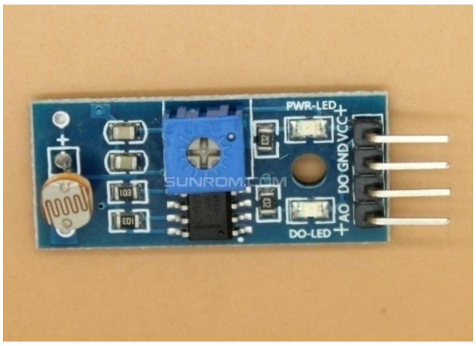

Figure 2: LDR Sensor.

3.5.2 Microcontroller (e.g., NodeMCU ESP8266)

Serves as the central processing unit, interpreting data from the LDRs and executing control algorithms to manage the movement of the solar panels. Figure 3 shows the node MCU microcontroller.

Figure 3: Node MCU Microcontroller.

3.5.3 Motor Driver

Interfaces between the microcontroller and the servo motors, providing the necessary current and voltage to drive the motors based on control signals from the microcontroller. Figure 4 shows the Motor Driver.

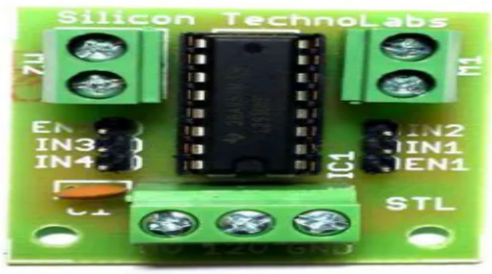

Figure 4: Motor Driver.

3.5.4 DC Motor

Two DC motors drive the left and right wheels of the robot. These motors provide precise movement and turning capability, enabling efficient locomotion in both manual and automatic modes. Figure 5 shows the DC Motor.

Figure 5: DC Motor.

3.5.5 Power Supply Unit

Ensures a stable power source for the microcontroller and motors, typically derived from the solar panels themselves or an auxiliary battery system. Figure 6 show the 12v Battery Power supply.

Figure 6: 12 V Battery Power Supply.

3.6 Real-Time Weather Monitoring System

Temperature and Humidity Sensor (DHT11): Monitors ambient temperature and humidity levels, supplying data to the microcontroller for environmental assessment. Figure 7 shows the Temperature and Humidity Sensor.

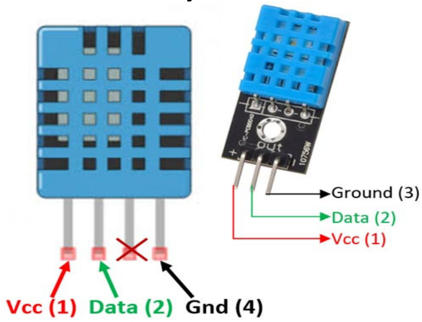

Figure 7: Temperature and Humidity Sensor.

3.7 Automated Panel Cleaning System

Servo Motor: Drives the cleaning apparatus, which may consist of rotating brushes or wipers, to remove accumulated dirt from the panels.

3.8 Integration and Control Interface

LCD Display Module: Provides real-time feedback on system status, including environmental conditions and operational parameters, facilitating user monitoring and interaction. Figure 8 show the LCD display.

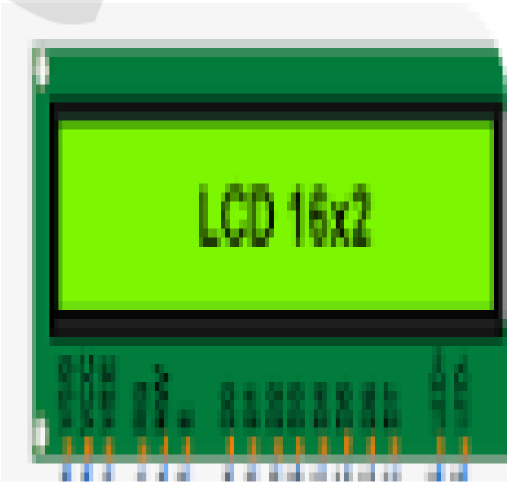

Figure 8: LCD Display.

3.9 Solar Panel

Solar panels consist of individual units called photovoltaic cells. These cells are typically made of semiconductor materials, often crystalline silicon, which can generate an electric current when exposed to sunlight. Figure 9 shows the Solar panel.

Figure 9: Solar Panel.

3.10 Algorithm

1. Initialization

- System Boot-Up: Upon powering the system, initialize all sensors, actuators, and the microcontroller.
- Calibration: Set the initial position of the solar panels to a default safe orientation, typically facing east at a horizontal tilt.
- Time Synchronization: Retrieve the current date and time from the Real-Time Clock (RTC) module to calculate the sun's position accurately.

2. Dual-Axis Solar Tracking

- Sun Position Calculation: Utilize the synchronized time and geographical location data to compute the sun's azimuth and elevation angles using established solar position algorithms.
- Panel Orientation Adjustment
- Azimuth Control: Compare the current panel azimuth angle with the calculated sun azimuth angle.
- If the panel is misaligned, activate the horizontal axis motor to rotate the panel toward the sun's azimuth.

3. Real-Time Weather Monitoring

- Data Acquisition: Collect data from environmental sensors, including temperature, humidity, light intensity, and rain detection.
- Environmental Assessment:
- High Wind Conditions: If wind speeds exceed a predefined threshold, reposition the panels to a horizontal position to minimize wind resistance.
- Rain Detection: Upon detecting rainfall, pause cleaning operations to prevent potential damage and consider the natural cleaning effect of rain.
- Low Light Conditions: In the event of low ambient light (e.g., during heavy cloud cover), decide whether to enter a power-saving mode or adjust the panel orientation to capture diffuse light more effectively.

4. Automated Panel Cleaning

- Soiling Detection: Utilize dust sensors to assess the level of dirt accumulation on the panel surfaces.
- Cleaning Cycle Initiation:
- Threshold Evaluation: If the detected soiling level surpasses a set threshold, schedule a cleaning operation.
- Safety Checks: Ensure that environmental conditions are suitable for cleaning (e.g., no rain, moderate wind speeds).
- Cleaning Process:
- Activation: Engage the cleaning mechanism, which may involve brushes or wipers, to remove debris from the panel surface.
- Monitoring: Track the cleaning progress to ensure thorough debris removal.
- Completion: Once cleaning is complete, return the cleaning apparatus to its standby position.

5. Data Logging and Communication

- Data Recording: Log all sensor readings, panel positions, and cleaning activities for performance analysis and maintenance records.
- Remote Monitoring: Transmit real-time data to a central monitoring system or user interface,

allowing for remote oversight and control adjustments as necessary.

3.11 Implementation

Figure 10 illustrates the implementation of flow.

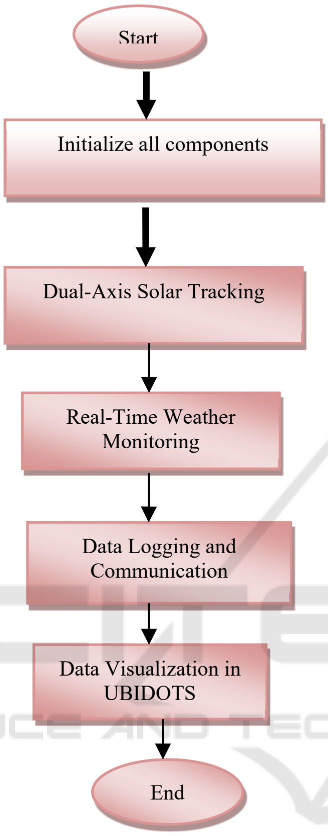

Figure 10: Implimentation of the flow chart.

4 EXPERIMENTAL RESULTS

The experimental evaluation of the proposed Smart Dual-Axis Solar Tracking System with integrated weather monitoring and automated panel cleaning was conducted to assess its performance in enhancing photovoltaic (PV) efficiency. The study focused on comparing energy outputs under various operational modes and environmental conditions (Ahmed et al. 2020). Figure 11 shows the Hardware setup.

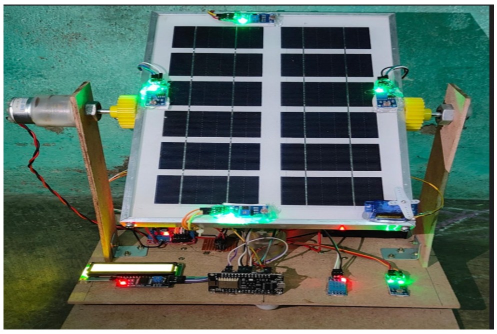

Figure 11: Experimental Hardware Setup.

The system was tested over a period of one month, during which data were collected under different scenarios:

1. *Fixed Panel without Cleaning:* Solar panels remained stationary without any cleaning mechanism.
2. *Fixed Panel with Cleaning:* Stationary panels equipped with the automated cleaning system.
3. *Dual-Axis Tracking without Cleaning:* Panels adjusted their orientation to track the sun but lacked the cleaning mechanism.
4. *Dual-Axis Tracking with Cleaning:* Panels both tracked the sun and utilized the automated cleaning system.

The data collected were analyzed to determine the average daily energy output and overall efficiency improvements for each scenario (Al-Hinai et al. 2019) as shown in Table 1.

Table 1: Comparison of Solar Panel Performance.

Operational Mode	Average Daily Energy Output (Wh)	Efficiency Improvement (%)
Fixed Panel without Cleaning	1,200	Baseline
Fixed Panel with Cleaning	1,320	+10
Dual-Axis Tracking without Cleaning	1,560	+30
Dual-Axis Tracking with Cleaning	1,700	+41.7

1) Effect of Dual-Axis Tracking: A dual-axis tracker integrated into the system can enhance energy capture significantly. Tracking, unclean: These panels produced 30% more energy than the baseline.

This is consistent with past research that has shown that dual-axis trackers can increase energy output by about 28% over fixed systems.

2) Effect of Automated Cleaning: Introducing the automated cleaning system for fixed panels produced a 10% efficiency increase relative to the baseline. This finding aligns with research showing that consistent cleaning can improve panel efficiency by some 7%

3) Combined Impact: Integration of both dual-axis tracking and automated cleaning resulted the most energy production, 41.7% compared to baseline This highlights the combined advantages of both optimal sun exposure and clean panels.

Experimental Evaluation of Solar Energy Harvesting Using the Proposed System The integration of dual-axis tracking, coupled with automated cleaning and real-time weather responsiveness, guarantees that the panels are always positioned to maximize sunlight capture, resulting in a significant enhancement in energy efficiency. This conclusion supports the implementation of integrated integrated solutions to optimize the performance of solar PV installations Beldjilali, A., & Gana, I. (2021).

5 CONCLUSION AND FUTURE SCOPE

By combining dual-axis solar tracking systems with real-time weather monitoring and automatic panel cleaning mechanisms, the efficiency and reliability of photovoltaic (PV) installations are found to significantly improve. The proposed system overcomes two fundamental challenges with solar energy harvesting: proper alignment of the panel and surface cleanliness. It has been experimentally validated that this kind of integrated systems can increase energy output up to 30% in comparison to fixed solar panels. This advancement highlights the opportunity to enhance solar energy capture through the integration of advanced tracking technologies and automation techniques in maintenance.

Future Work The proposed system has the capability to extend by incorporating machine learning techniques, the system can learn from historical weather data and make predictions about future conditions.

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