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Design and Implementation of IoT-Based Solar Tracking System

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Abstract - *To increase the efficiency of photovoltaic (PV) panels, this study presents the design and development of a dual-axis solar tracking system based on Arduino. Traditional fixed solar panels are less energy efficient overall because they only produce their maximum power during a few hours of the sun's rays. The suggested system uses Light Dependent Resistors (LDRs) to detect the amount of sunlight and an Arduino Uno microcontroller to process the signals to solve this problem. The solar panel is oriented both horizontally and vertically by means of servo motors, which guarantee that it faces the sun all day long. The system is a realistic, economical, and sustainable method of utilizing solar energy because it is built for real-time responsiveness, dependability, and resistance to environmental influences. By providing a simple but efficient tracking mechanism, this work advances solar power technology and highlights its potential for broad use in both residential and commercial settings.*

Keywords: Dual-axis solar tracker, Arduino Uno, Photovoltaic panels, Light Dependent Resistors (LDRs), Servo motors, Renewable energy, Energy efficiency.

1. INTRODUCTION

The use of renewable energy sources has increased due to the world's expanding energy needs, worries about the depletion of fossil fuels, and environmental damage. Because it is plentiful, clean, and sustainable, solar energy is one of the most promising substitutes among these. However, the fixed orientation of photovoltaic (PV) panels frequently limits their efficiency, allowing maximum power generation only when the sun is perpendicular to the panel surface. Due to the sun's constant movement across the sky, fixed panels are less effective overall because they are unable to capture the best amount of sunlight throughout the day.

To solve the limitations of fixed solar panels, engineers have developed solar tracking systems that automatically adjust the position of panels to follow the sun's path. The first trackers appeared in the 1980s and were mainly used for large-scale projects. However, with advances in microcontrollers, sensors, and motors, solar trackers have become more affordable and practical, making them suitable for homes and businesses as well.

Solar trackers are generally divided into two types: **single-axis** and **dual-axis**. Single-axis trackers tilt the panels in one direction, which works well in tropical regions. Dual-axis trackers, on the other hand, move both horizontally and vertically, capturing more sunlight and delivering higher efficiency in different locations.

Studies have shown clear benefits. Single-axis trackers can boost energy production by **10–25%**, while dual-axis systems can achieve **27–50% or more**, depending on their design and environment. Most modern systems use **Light Dependent Resistors (LDRs)** to detect sunlight, along with **servo motors** and microcontrollers such as the **Arduino Uno** to keep the panels precisely aligned in real time. Some advanced systems even combine **sensor-based tracking** with scheduled movement and monitoring tools like LabVIEW for smarter control.

Beyond improving panel performance, solar tracking systems also make solar energy more cost-effective, sustainable, and quicker to pay back on investment. As the world pushes for greener technologies and reduced carbon emissions, automatic solar trackers are emerging as a key part of the future, helping bridge the gap between the potential of solar energy and its real-world use.

2. Literature Survey

1. LDR-based Single-Axis Tracker with Fuzzy Logic Control

Authors: Sharma et al.
Year: 2023
Publication: International Journal of Renewable Energy Research
Key Highlights:
Method: Used Light Dependent Resistors (LDRs) for sunlight detection, combined with fuzzy logic-based control for a single-axis solar tracker.
Advantages: Low-cost sensing mechanism, relatively simple to implement, suitable for small-scale PV systems.
Disadvantages: Sensitive to dirt, shadows, and cloudy weather, which reduces accuracy.
Performance: Achieved about 15–20% more energy compared to fixed-tilt panels.
Impact: Demonstrated the effectiveness of fuzzy logic for improving tracking response but highlighted the need for robust sensors in real-world conditions.

2. Single-Axis Tracker with Encoder Feedback and PID Control

Authors: Patel et al.
Year: 2022
Publication: Renewable Energy Journal
Key Highlights**:**
Method: Designed a single-axis tracker that integrates encoder feedback with PID control for precise positioning.
Advantages: More accurate alignment with the sun, minimizes error compared to sensor-only systems.
Disadvantages: Higher mechanical complexity and cost due to the encoder system.
Performance: Delivered 18–25% efficiency gain compared to fixed panels.
Impact: Showed the potential of integrating control theory with solar tracking, making it more reliable for commercial use.

3. Open-Loop Astronomical Single-Axis Tracker

Authors: Khan et al.
Year: 2021
Publication: Solar Energy Journal
Key Highlights:
Method: Implemented an open-loop astronomical model, where the tracker adjusts based on calculated sun position (time and location).
Advantages: No need for sensors, reduces chances of errors due to shadows or dirt.
Disadvantages: Requires accurate calibration and precise location/time data; not adaptive to sudden weather changes.
Performance: Achieved 15–22% more energy output compared to fixed panels.
Impact: Proved that astronomical tracking is a low-maintenance alternative but lacks flexibility in dynamic conditions.

4. Fuzzy Logic-Based Single-Axis Tracker

Authors**:** Kumar et al.
Year: 2021
Publication: International Conference on Control & Automation
Key Highlights:
Method: Used fuzzy logic algorithms to manage solar panel orientation along a single axis.
Advantages: Provides smoother control compared to basic threshold-based systems, adapts to varying sunlight intensity.
Disadvantages: Requires careful tuning of fuzzy rules, which may complicate implementation.
Performance: Showed 20–23% efficiency improvement over fixed panels.
Impact: Contributed to the adoption of AI-inspired control systems in renewable energy, demonstrating flexibility in uncertain weather.

5. Computer Vision-Assisted Single-Axis Tracker

Authors: Silva et al.
Year: 2020
Publication: Journal of Solar Energy Engineering
Key Highlights:
Method: Integrated camera-based image processing with solar panel movement to detect sunlight direction.
Advantages: Accurate alignment, independent of LDR or sensor errors caused by dust/shadows.
Disadvantages: Requires more power for image processing; performance affected by fog, dust, or glare.
Performance: Reported 22–25% gain in efficiency compared to fixed tilt systems.
Impact: Highlighted the potential of computer vision in solar energy but raised challenges of cost and power consumption for small-scale use.

6. Sensor-less Single-Axis Tracker (Current/Voltage-Based)

Authors: Ahmed et al.
Year: 2019
Publication: IEEE Access
Key Highlights:
Method: Used current and voltage feedback from the PV panel itself (no external sensors) to detect optimal alignment.
Advantages: Reduced hardware requirements, simpler design, avoids sensor failure.
Disadvantages: Slower response during rapidly changing weather conditions.
Performance: Produced 15–20% more power compared to fixed panels.
Impact: Proved that sensor-less systems are practical and reduce cost but require improvement in response speed.

7. IoT-Enabled Single-Axis Tracker Authors:

Mehta etal.
Year: 2018
Publication: International Journal of Smart Grid
Key Highlights:
Method: Designed a single-axis tracker with IoT connectivity, enabling remote monitoring and control.
Advantages: Allows predictive maintenance, reduces downtime, and integrates with smart grids.
Disadvantages: Increases cybersecurity risks and dependence on internet connectivity.
Performance: Achieved 15–20% efficiency gain plus reduced operational downtime.
Impact: Demonstrated how IoT integration can make solar tracking smarter, paving the way for future smart energy systems.

3. Objective

The objective of a solar tracking system using Arduino can be summarized as follows:

Maximize Solar Energy Capture: The primary goal is to continuously orient solar panels towards the sun's position throughout the day, maximizing the amount of sunlight incident on the panel surface. This directly leads to higher energy generation compared to fixed solar panel installations.

Increase System Efficiency: By optimizing panel alignment, the system aims to enhance the overall efficiency of solar energy harvesting, ensuring that the solar panels operate closer to their maximum power point.

Improve Power Output: The system seeks to significantly increase the electrical power output (voltage and current) generated by the solar panels, resulting in greater energy yield over a given period.

Optimize Energy Utilization: For systems with battery storage, the objective includes ensuring efficient charging of batteries by maximizing the energy input from the solar panels.

Reduce Dependency on Fixed Installations: The system aims to provide a more dynamic and efficient alternative to static solar panel setups, which are limited by a fixed orientation and cannot adapt to the sun's movement.

Cost-Effectiveness and Accessibility: Utilizing an Arduino microcontroller and readily available components like LDRs and servo motors allows for the development of a relatively low-cost and accessible solar tracking solution, suitable for various applications.

Educational and Research Platform: Arduino-based solar trackers serve as excellent platforms for learning about electronics, programming, renewable energy, and automation, facilitating educational and research initiatives.

4. Proposed Methodology

Initialization:

The system begins by powering up through the power supply. The Arduino microcontroller initializes its input and output pins, establishes communication with the LDR sensors, and prepares to control the servo motor.

Light Sensor Data Collection:

Two Light Dependent Resistors (LDR1 and LDR2) are used as sunlight sensors. They continuously detect the intensity of sunlight. The Arduino reads their analog voltage values, which vary according to the amount of light falling on them.

Comparison of Sensor Values:

The Arduino compares the readings from LDR1 and LDR2:

If both sensors receive nearly equal light intensity → the solar panel is already aligned with the sun, and no movement is required.

If one sensor receives more sunlight than the other → the Arduino determines the required direction of movement to balance the readings.

Servo Motor Control:

Based on the comparison, the Arduino sends a PWM control signal to the servo motor. The servo motor rotates in small steps, shifting the solar panel toward the direction of maximum sunlight until the two LDR readings are balanced.

Solar Panel Adjustment:

The solar panel, mounted on the servo motor shaft, rotates accordingly. This ensures that the panel is always aligned perpendicularly to the incoming sunlight, optimizing energy absorption.

Continuous Tracking:

Throughout the day, as the sun moves across the sky, the readings of LDR1 and LDR2 change. The Arduino continuously monitors and adjusts the solar panel orientation via the servo motor to keep it aligned with the sun’s position.

Power Supply and Efficiency:

The system operates on a regulated DC power supply, ensuring uninterrupted function of the Arduino, sensors, and servo motor. By dynamically tracking and aligning the panel, the system maximizes solar energy harvesting, improving the overall efficiency of power generation.

6. Conclusion

Solar tracking systems help solar panels work more efficiently by automatically following the sun’s movement throughout the day. Trackers built with Arduino, LDR sensors, and servo motors have shown to be reliable, affordable, and effective, even in low-light conditions. Studies have found that these systems can produce more energy than fixed solar panels, making them especially useful in rural areas and developing countries. In the future, using more sensitive and low-power sensors could make these systems even better and cheaper, showing great promise for improving the use of renewable energy worldwide.

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