DEVELOPMENT OF SUN TRACKER MODEL FOR THE IMPROVEMENT IN EFFICIENCY OF SOLAR PANEL

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Abstract - *A sun tracker is an automated device designed to adjust the orientation of solar panels to follow the sun's trajectory across the sky, maximizing the amount of direct sunlight they receive. Unlike stationary solar panels that capture sunlight at a fixed angle, these dynamic systems use sensors like Light-Dependent Resistors (LDRs) and microcontrollers such as the Arduino Nano to ensure the panels remain perpendicular to the sun's rays throughout the day. This project demonstrates a prototype that integrates these components with motor drivers to significantly enhance solar energy harvest, improving overall system efficiency by 20–40% compared to static installations. The detailed engineering of this system involved creating 3D models using Fusion 360 and integrating a tracking mechanism consisting of driving motors and a controller specifically, the ESP32 and Arduino Nano were utilized to handle complex tracking algorithms and provide real-time data monitoring via OLED displays. The system's ability to maximize power generation makes it highly beneficial for various applications, including residential power, irrigation, and electric vehicle charging. While tracking systems involve higher initial costs due to the required sensors and mechanical modules, the substantial increase in energy yield leads to a faster return on investment and promotes the long-term sustainability of renewable energy solutions By reducing reliance on fossil fuels and minimizing greenhouse gas emissions, sun tracking technology represents a cost-effective and environmentally friendly advancement that highlights the potential for innovative technology to address global energy challenges*

***Key Words*: Sun Tracker, Solar Panel Efficiency, LDR Sensors, Arduino Nano, ESP32, Renewable Energy, Dual-Axis Tracking, Sustainability**

1. INTRODUCTION

A sun tracker is an automated device designed to adjust the orientation of solar panels to follow the sun's movement across the sky. These systems act as "smart robots" for solar energy installations, functioning similarly to sunflowers that turn their faces toward the sun. The primary objective of a sun tracker is to maintain the solar panel at an angle perpendicular to the sun's rays, thereby maximizing the absorption of sunlight. While stationary panels capture energy at a fixed angle often losing efficiency as the sun moves tracking systems dynamically adjust to ensure constant, direct exposure. This enhancement in solar energy utilization aims to increase the energy yield of solar panels by 20–40% . Such improvements contribute directly to the sustainability and cost-effectiveness of renewable energy solutions, particularly in high-demand environments.[1]

Traditional solar panels consist of photovoltaic (PV) cells arranged in arrays to excite electrons using photons from solar radiation. However, the efficiency of these cells depends heavily on the angle of incidence. Static panels suffer from limited efficiency because they only achieve an orthogonal (90°) angle with sunrays for a brief period each day, the utilization of high-sensitivity sensors is critical for determining optimal light power consumption. To address these pitfalls, solar tracking systems were introduced to maintain this 90° angle continuously. A comprehensive tracking system is composed of three primary modules: the mechanism (framework), the driving motors, and the tracking controller [2]

Single-Axis Trackers: These track movement in one dimension (either East-West or North-South). They are simpler and less expensive but offer lower efficiency gains.

Dual-Axis Trackers: These follow the sun in both horizontal and vertical dimensions. While they involve higher mechanical complexity and cost, they provide the highest possible energy conversion efficiency [3].

2. METHODOLOGY

The development of the autonomous sun tracker followed a structured engineering process to ensure reliability and performance.

2.1. System Design

1. **Specifications:** Defining tracking range and desired accuracy.
2. **Conceptual Design:** Creating initial 3D models and diagrams to visualize components.
3. **Detailed Engineering:** Utilizing CAD software (Fusion 360) to refine the mechanical framework and perform structural analysis.
4. **Prototype Development:** Fabricating components via 3D printing and laser cutting for assembly.

2.1.1. Hardware Integration

The system integrates several high-precision components to ensure operational stability:

- **Microcontrollers:** An ESP-32 for high-level processing and Wi-Fi diagnostics, paired with an Arduino Nano for real-time sensor data processing.

- **Sensors:** Four LM393 LDR control modules for light detection and an AW2302 (DHT22) sensor for ambient temperature and humidity monitoring.
- **Power Management:** An LM2596S DC Buck Converter serves as a step-down voltage regulator to maintain a stable supply, while 1N4148 fast-switching diodes prevent current backflow.
- **Actuation and Feedback:** An L298N motor driver controls DC motors with durable metal gears. An OLED display module provides real-time visual feedback on orientation and intensity.

2.1.2 Software and Control

The control logic, implemented via the Arduino IDE, utilizes a threshold-based algorithm. The system compares intensity between LDRs with a programmed threshold **of 250 units**. If the difference exceeds this value, the motors actuate at a speed **of 80 (approximately 50% PWM)** until alignment is restored. Simultaneously, the ESP32 hosts a web-based "ESP32 Monitor" dashboard,

Figure 1-Working Model

Displaying real-time voltage and temperature history.

2.1.4 Working Process

The implementation followed a precise sequence:

1. Building the physical framework (Body) using 3D printed models.
2. Mounting electrical components and solar panels.
3. Establishing electrical connections via a high-density breadboard.
4. Simulating the control code and threshold logic.
5. Creating and simulating the web page interface via a local IP.
6. Final testing under various environmental conditions.

3. Materials and Results

Table -1: Parts and Quantity Required

Sl No.	Parts	Quantity
1	Servo Motor	1
2	Motor drive (1298)	1
3	Processing Unit (Arduino Nano)	1
4	Arduino Cable	1
5	Breadboard	1
6	LDR Sensor	4
7	Adaptor	1
8	DC Female Jack	1
9	Jumper Wire	40
10	Solar Panel (6x6)	4
11	ESP32	1
12	Nut & Bolt 1/2inc 4mm	6
13	Washer d=4mm	12
14	Nut & Bolt 2inc 4mm	6
15	Humidity Sensor	1
16	Voltage Sensor	1
17	Adaptor Plate	1
18	Frame Work	1
19	Other	1

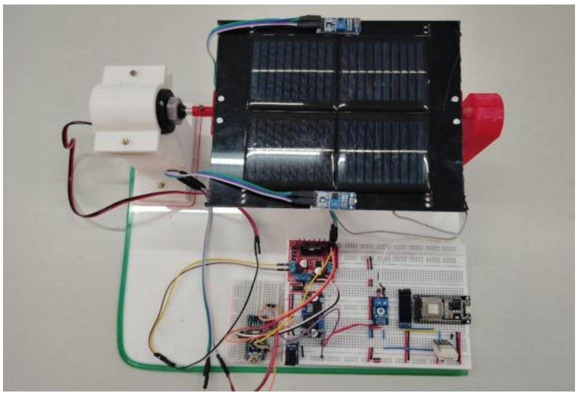

Fig -2: ESP32 Moniter Results

Based on the project report, the **results** of implementing the sun tracker model are as follows:

1. Enhanced Energy Efficiency

The primary result of this project is a significant increase in energy harvest. By ensuring that solar panels remain perpendicular to the sun's rays throughout the day, the tracking system enhances energy yield by **20–40%** compared to static solar installations,. Under optimal conditions, this increase in energy production can reach up to **45%.**

2. Successful Automated Tracking

The prototype demonstrated successful automation using a combination of **LDR sensors** and microcontrollers (**Arduino Nano** and **ESP32**).

- The system accurately detects variations in light intensity to determine the sun's position.
- The **L298N motor driver** and **DC motors** provide precise rotational movement to adjust the panel's orientation in real-time.

3. Real-Time Data Monitoring

The integration of the **ESP32** and an **OLED display** allowed for successful real-time monitoring of system performance,. The results showed that the system could capture and display:

- **Voltage:** Real-time generation data from the solar panel,.
- **Environmental Data:** Ambient temperature and humidity levels measured by the **DHT22/AW2302 sensor**,.
- **Web Interface:** A web-based monitor was successfully created to visualize voltage and temperature trends over time through graphs and history tables.

4. Cost and Design Validation

- **Material Cost:** The total expenditure for the prototype was calculated at **2446 units**, demonstrating that the system is relatively affordable for its efficiency gains.
- **Prototyping:** The use of **3D printing** (for frames and mounts) and **CAD software (Fusion 360)** resulted in a mechanically sound and reliable tracking mechanism.

5. Environmental Impact

The system successfully promotes sustainability by maximizing the output of renewable energy, thereby reducing reliance on fossil fuels and contributing to a reduction in greenhouse gas emissions,

In summary, the tracker effectively transforms a passive solar setup into an active, high-performance system that is both cost-effective in the long term and highly efficient,.

4. CONCLUSIONS

The implementation of a sun-detecting solar panel system represents a significant advancement over traditional static installations. By maintaining a perpendicular angle to the sun's rays, the system maximizes energy absorption and ensures optimal power generation throughout the day. The integration of the ESP32 and Arduino Nano provides a robust, user-friendly platform for automated renewable energy. Ultimately, such innovations address global energy challenges by increasing the efficiency of solar sources and paving the way for a sustainable, green future.

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