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SUN-TRACKING SOLAR PANELS WITH ADAPTIVE PROTECTIVE SHIELDING: A SOLUTION FOR OPTIMAL PERFORMANCE AND RESILIENCE

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Abstract :
Effective solar panel systems are becoming more and more important as solar energy gains traction as a major environmentally friendly and sustainable energy source. In order to maximise energy harvesting, this project presents a solar panel system with sun-tracking capabilities that can precisely track the sun's path throughout the day. Furthermore, the system has a barrier that automatically moves to protect the solar panels from outside influences, such as hailstorms. The shield's synchronisation with the solar panel guarantees flexible and all-encompassing defence. To further increase the system's adaptability, an LED function has been included. By giving consumers timely information, solar panels' lifespan and efficiency may be extended and users can take the necessary precautions to protect them. In addition, the system integrates with a data science-based rainfall prediction project by using real-time sensor input. Rainfall prediction is formulated as a binary classification problem based on meteorological predictors. The random forest model is trained on historical weather data from Pune, India. The model (Random Forest Algorithm) is fed real-time sensor data to forecast rainfall and alert users appropriately. The proposed approach provides an interpretable and high-accuracy solution to short-term rainfall prediction. It has significant advantages over numerical prediction models in terms of computational efficiency and ease of implementation. This combination of technologies improves the system's resilience and flexibility to changing climatic circumstances by enabling proactive decision-making based on precise weather forecasts. The project provides consumers with a complete solution for sustainable energy generation by delivering a trustworthy, adaptable, and resilient solar panel system that maximises energy output and extends the lifespan of the solar panels.

Keywords: *Sun-tracking,Protective shield ,Renewable energy,rainfall prediction,weather forecasting*

I. INTRODUCTION

Making use of solar power via photovoltaic panels is still a major part of the global effort to find sustainable energy sources. To maximize the efficiency of solar panels, however, is a tough problem due to the inherent unpredictability in sunlight angle and exposure. Solar tracking systems, which dynamically orient solar panels to monitor the sun's movement and maximize energy output, have emerged as a critical option to handle this difficulty. In-depth evaluation and analysis of numerous solar tracking systems are covered in this research study, with an emphasis on sun tracking solar panels with IoT integration. These cutting-edge systems include advanced protection mechanisms to prevent unfavorable climatic circumstances in addition to real-time panel positioning adjustments for maximum sunlight absorption. Moreover, these systems have IoT integration platforms that allow for remote control and monitoring, like Blynk. This paper investigates the integration of Sun Tracking Solar Panels with the Blynk app for improved monitoring and control, in addition to discussing the effectiveness of solar tracking systems. The integration makes it easier to see important data on the Blynk app interface, such as voltage outputs. Through the app's UI, users may remotely view and monitor real-time voltage measurements and also change the panel shield's orientation. By means of an extensive assessment of diverse tracking techniques and IoT integration, this study endeavors to determine the most efficacious approaches for maximising solar panel efficiency. It examines the benefits and drawbacks of sun tracking solar panels, highlighting how they can increase energy output while providing reliable protection methods and intuitive user interfaces with the Blynk app. The purpose of the research paper presented here is to highlight how important it is for integrated Sun Tracking Solar Panels and IoT platforms to improve photovoltaic panel productivity and usability for the production of sustainable energy. Through the integration of cutting-edge tracking technologies with Internet of Things capabilities, this study aims to offer practical guidance on optimizing solar energy harvesting efficiency while guaranteeing user accessibility and system security.

II. LITERATURE REVIEW

The solar tracker built using Arduino technology that uses resistors that depend on light (LDR) as sensors is presented in this study. This method maximises electricity output by strategically placing solar panels to follow the course of the sun. An Arduino board, servo motors, Bluetooth module, LDR sensors, and an LCD display are some of its parts. The tracker's tilt angles are modified by a control algorithm that examines sensor data. A comparative investigation indicates a power output gain of 11.57% over fixed tilt systems. In conclusion, by precisely following the movement of the sun, the Arduino-based solar tracker using LDR sensors greatly improves the performance of solar panels.[1].

The benefits of using a straightforward solar tracking system with an electric stepper motor and a light sensor are investigated in this study. This technique makes sure that the solar panel is always facing the direction of the sun's rays, which should increase the efficiency of power generation. In a regulated experimental setting, we design, build, and assess a sun-tracking device.We report the design details as well as the experimental outcomes. [2].

The photovoltaic (PV) market is still growing, which is making the situation in the PV business more difficult.A variety of cell types are offered by an increasing number of cell providers as they arise in the market.Owing to a scarcity of silicon in previous years, solar cells were becoming noticeably thinner in the last several years.Each of these characteristics has the potential to have an effect on the mechanical stability of a solar panel. This study investigates the effects of cell thickness, interconnection method, and cell supplier on the mechanical stability of solar cells inside solar panels. Industry-recognized test procedures were used to evaluate the structural stability of solar panels, and for an additional analysis, other analytical methods such IV curves and electrical luminescence pictures were used. The study shows, among other things, that as cell thickness decreases, solar cells' mechanical stability significantly decreases. This underscores the need for more research on the rapidly declining wafer thickness that affects the photovoltaic industry, which calls for modifications to solar cell and module manufacturing procedures. [3].

Conventional techniques, which are often referred to as maximum power point tracking (MPPT) methods, work well in conditions of uniform sun irradiation.However, due to the possibility of many local maxima on the power-voltage characteristic curve, conventional Maximum Power Point

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Trackers (MPPTs) may not operate successfully in instances of solar irradiance mismatch, particularly under partly shaded conditions (PSCs). While some academics have looked at Real Maximum Power Point Tracking (RMPPT) techniques for these kinds of situations, these systems are frequently complicated and need extra circuits or resources.This study proposes a unique MPPT method that can achieve RMPPT under PSCs.The usefulness of the proposed MPPT method is investigated with respect to the RMPP position, and the conclusions are validated by means of simulation and testing. [5].

The author of this study created a solar panel that optimises the amount of sunlight by using the concept of an open loop.Panel placement has affected how much time the author has spent writing.This suggests that the panel would continue to rotate, consuming unnecessary energy, even in the absence of sunlight. [7].

The author constructed a solar tracking system, which was tested in many locations and comprised of light sensors.The model comprised a quadrate array of sensors consisting of four LDRs, a potentiometer, servo motors, and a microcontroller.The disadvantage of this technique is the servo motors.The whole weight of the panel would not be viable to include in the design as a load on the motors due to the servo motor's severely limited rotation capability and exorbitant power consumption. [8].

This study introduces a suntracking solar panel system designed to enhance energy collection efficiency. The system employs a solar panel with a servo mechanism that tracks the sun's path, optimizing energy capture throughout the day. Research findings indicate that the suntracking system surpasses stationary solar panels, achieving a remarkable 30% boost in energy collection[22].

III. METHODOLOGY

The process includes combining advanced weather forecasting and rainfall detection systems with sun monitoring technologies. This method optimises energy production and protects solar panel infrastructure by combining sun tracking principles, precise weather predictions, and proactive preventive actions.

1. **Sun Tracking Technology:**
    - Moves a solar panel that is fixed on a specially-made platform with the help of a single motor and a NodeMCU microprocessor.
    - The stand holds the motor and solar panel in place, making it easier to track and optimise sun exposure all day long.
    - By sensing changes in light intensity, two LDR sensor modules that are placed on opposite side of the solar panel help track sunlight.

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THEORY OF USING TWO LDR:

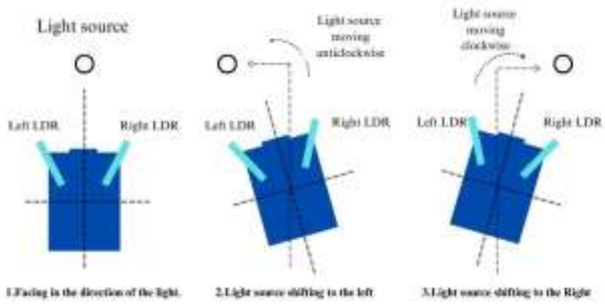

FIGURE:1

The light-dependent resistor (LDR) installation layout within a system is shown in the diagram. When the two LDRs' observed light intensities converge, a state of stability is reached. The main light source—the sun—follows a westward path, causing varying amounts of light to strike the two LDRs at different intensities. A microcontroller-integrated algorithm is designed to detect changes in light intensity and then initiate motorised adjustments to line up the solar panel with the sun's path. This guarantees synchronised tracking of the movement of the light source, maximising the efficiency of harvesting solar energy.

2. **Weather Prediction Integration**:
   - Incorporates weather forecasting data obtained from sources like online APIs or local weather stations.
   - The NodeMCU microcontroller processes weather data to anticipate changes in sunlight intensity and adjust the solar panel's orientation accordingly.
   - By preemptively aligning the panel with predicted sunlight patterns, the system optimizes energy capture and enhances overall efficiency.
3. Rainfall Detection and Protective Measures:
   - Implements rainfall detection sensors to identify precipitation events and protect the solar panel from damage.
   - Upon detecting rainfall, the system activates a protective shield mechanism to cover the solar panel surface.
   - The shield, deployed automatically by the NodeMCU, shields the panel from rainwater, preventing potential short circuits or corrosion.

THEORY OF PROTECTIVE COVERING:

The purpose of the solar panel shield is to screen the photovoltaic surface from potentially damaging weather, debris, and other external factors. Usually, it consists of a sturdy covering or structure that is placed over the solar panels with purpose. By serving as a barrier against environmental factors like rain, snow, dust, or physical damage, this shield increases the solar panels' lifespan and efficiency.The solar panel shield has a controlled rotating mechanism thanks to the use of a servo motor. The servo motor rotates the shield when pressed by a button or via an IoT interface such as the Blynk app. When necessary, this rotation modifies the shielding angle to provide the solar panels with the best possible exposure to sunlight.User interaction and control over the solar panel shield's rotation are made possible by a button interface. The servo motor and the button are activated when the button is pressed, starting the shield's rotation. To enable user interaction with the shield rotation system, the button mechanism can be incorporated into a control unit, like an Arduino or microcontroller.

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THEORY BACKGROUND BEHIND SOLAR TRACKING
EARTH ROTATION & REVOLUTION

Over the course of a day, the sun's location fluctuates constantly, mostly due to Earth's movements. The two main sorts of movements that these include are the Earth's orbit around the sun and its rotation on its own axis. The cycle of day and night is brought about by Earth's rotation, sometimes known as "rotation." An entire rotation of the Earth on its axis, from west to east, takes around 23 hours and 56 minutes overall.

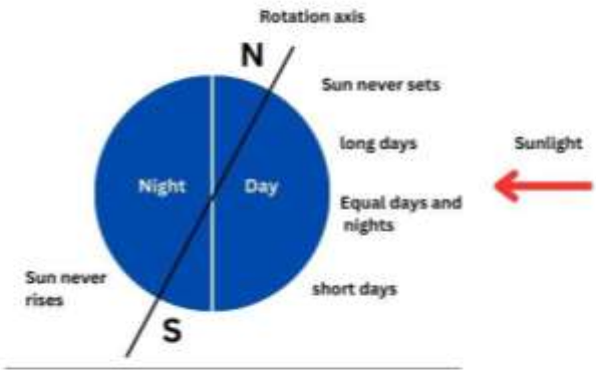


FIGURE 2:

The yearly orbit of Earth around the Sun, which travels an elliptical route for 365 days and forms an elliptical plane, is what causes seasonal variations. Variations in sunlight exposure occur throughout the year at various latitudes due to the tilt of Earth's rotating axis, which is around 23.5 degrees relative to this plane. Together with the elliptical orbit of Earth, this axial tilt determines the summer and winter solstices as well as the spring and autumn equinoxes, which affect global temperature variations and weather patterns.

The sun emits radiation at a relatively constant rate over time, and the solar constant refers to the strength of that radiation when it strikes a specific section of the earth's crust. This solar constant's value can be stated as:

$$G = \sigma T^4 \left(\frac{4\pi R^2}{4\pi D} \right) = 1367 Wm^{\ 2}$$

$$\alpha = 90 + \varphi - \delta$$

Subtract the result from 180° if the above equation yields a number higher than 90°. It indicates that, as is customary in the northern hemisphere, the sun is rising from the south at noon.
The site of interest's latitude, represented by φ, is +ve in the northern hemisphere and −ve in the southern hemisphere. The declination angle, δ, varies according to the day of year.

Sunrise= $12 - \frac{1}{15^\circ}\cos^{-1}(-\tan\varphi\tan\delta) - \frac{TC}{60}$

Sunset= $12 + \frac{1}{15^\circ}\cos^{-1}(-\tan\varphi\tan\delta) - \frac{TC}{60}$

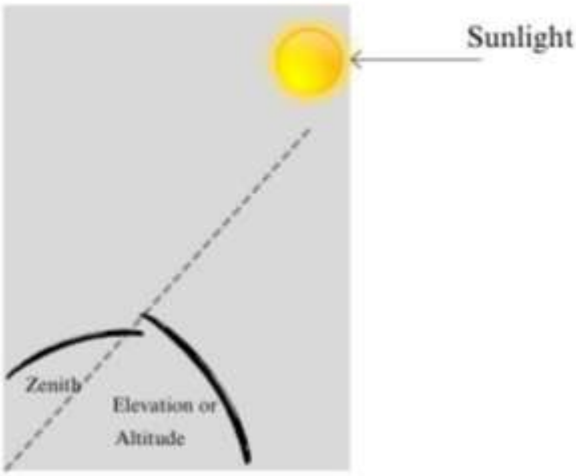


FIGURE 3:

Like the elevation angle, the zenith angle quantifies the angle vertically. As 90° subtracted the elevation angle

(Zenith Angle = 90° - elevation angle = 90° - α)

it indicates the angle between the sun and the vertical plane. The azimuthal angle shows the direction the sun is coming from on a compass. In the southern hemisphere, solar noon is straight north, whereas in the northern hemisphere, it is south. The azimuth angle varies during the day. At the equinoxes, the sun rises exactly east and sets directly west, regardless of latitude. Consequently, the azimuth angles are 90 degrees at dawn and 270 degrees at nightfall.

Where φ being the latitude of the place, δ being the declination angle and TC is the Time Correction

- **TYPE OF SOLAR TRACKER USED**

Single Axis Tracker :

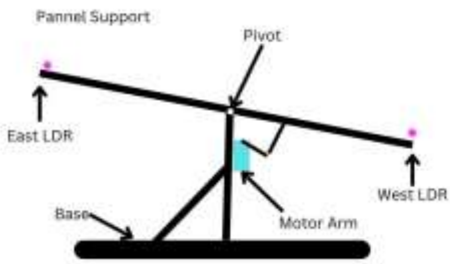


FIGURE 4:

- Operates in one primary cardinal direction.
- Utilizes a single-row tracking setup.
- Demonstrates increased reliability.
- Boasts an extended operational lifespan.

Single-axis trackers can be categorized into several common types, including:

- Horizontal Single Axis Trackers (HSAT).
- Horizontal Single Axis Trackers with Tilted Modules (HTSAT).

- Vertical Single Axis Trackers (VSAT).
- Tilted Single Axis Trackers (TSAT).
- Polar-Aligned Single Axis Trackers (PSAT).

4. Benefits and Implications:
   - By integrating sun tracking with weather prediction and rainfall detection, the system maximizes energy generation while mitigating potential damage from adverse weather conditions.
   - Improved efficiency and protection enhance the reliability and longevity of solar panel installations, contributing to sustainable energy production.

   - The merged theory represents a holistic approach to solar energy management, leveraging advanced technologies to optimize performance and resilience in varying environmental conditions

By merging sun tracking technology with weather prediction and rainfall detection, the project achieves a comprehensive solution for maximizing solar harvest and protecting solar panel infrastructure, ushering in a new era of efficiency and sustainability in solar energy utilization.

THEORY OF PROTECTIVE COVERING

The purpose of the solar panel shield is to screen the photovoltaic surface from potentially damaging weather, debris, and other external factors. Usually, it consists of a sturdy covering or structure that is placed over the solar panels with purpose. By serving as a barrier against environmental factors like rain, snow, dust, or physical damage, this shield increases the solar panels' lifespan and efficiency.

The solar panel shield has a controlled rotating mechanism thanks to the use of a servo motor. The servo motor rotates the shield when pressed by a button or via an IoT interface such as the Blynk app. When necessary, this rotation modifies the shielding angle to provide the solar panels with the best possible exposure to sunlight.

User interaction and control over the solar panel shield's rotation are made possible by a button interface. The servo motor and the button are activated when the button is pressed, starting the shield's rotation. To enable user interaction with the shield rotation system, the button mechanism can be incorporated into a control unit, like an Arduino or microcontroller.

Benefits of the system:

- **Protection**: The shield guards the solar panels against environmental factors, preserving their efficiency and lifespan.
- **Integration**: Combining a user-friendly button interface with servo motor control offers a simple yet effective means of managing solar panel protection and positioning.
- **Increased Lifespan:** Minimized exposure to harsh weather conditions and reduced contamination translates to a longer operational life for the solar panels. By preserving their structural integrity and functionality, the shield contributes to an extended lifespan for the panels, maximizing their return on investment over time.
- **User Accessibility and Convenience:** The integration of a button-controlled servo motor offers a user-friendly interface.
- **Proactive Weather Protection:** The system can proactively shield the solar panels from adverse weather conditions like intense rain by integrating rainfall prediction using sensor data. The system further improves its dependability and efficiency by guaranteeing little damage and downtime through early alerts and preventative actions.

IV RESULTS AND DISCUSSION

A. Comparative Analysis with Previous Systems

In comparison with existing solar tracking systems [2], the implemented system demonstrated several notable advantages. The system's simplified design, reduced energy consumption, and improved user accessibility set it apart in terms of practicality and efficiency. These advantages position the implemented system as a promising solution for maximizing solar panel performance in real-world applications.

B. Integration of system with data science

The random forest model exhibited strong performance across multiple metrics on the dedicated test set. It achieved an impressive overall accuracy of 82.4%. More notably, the model demonstrated a recall of 0.81, signifying its ability to reliably identify rainy days.The simplified formula for calculating the Gini index provided an efficient means to handle class imbalance in binary classification problems, streamlining the process by eliminating the need to compute individual class probabilities and complements.

The development of the rainfall prediction model using a random forest classifier and its evaluation on historical meteorological data from Pune, India yielded significant insights and promising outcomes.

Class Imbalance and Gini Index:

An essential aspect of this study was assessing the class imbalance within the dataset. The Gini index, a valuable tool for quantifying distribution inequality, was used to gauge the extent of imbalance in the data. The calculated Gini index of 0.62 indicated a substantial class imbalance, with 38% of days marked as rainy and 62% as non-rainy. This imbalance highlighted the need to prioritize evaluation metrics that consider class distributions over the conventional overall accuracy.

Model Performance:

The random forest model exhibited strong performance across multiple metrics on the dedicated test set. It achieved an impressive overall accuracy of 82.4%. More notably, the model demonstrated a recall of 0.81, signifying its ability to reliably identify rainy days. The balanced performance across both classes was evident in the F1 score, which reached 0.82.

Comparing this random forest model to logistic regression, a substantial improvement in recall was observed, rising from 0.77 to 0.81. This improvement underscores the effectiveness of the random forest model in addressing class imbalance and improving its predictive power.

Discussion and Implications:

The simplified formula for calculating the Gini index provided an efficient means to handle class imbalance in binary classification problems, streamlining the process by eliminating the need to compute individual class probabilities and complements.

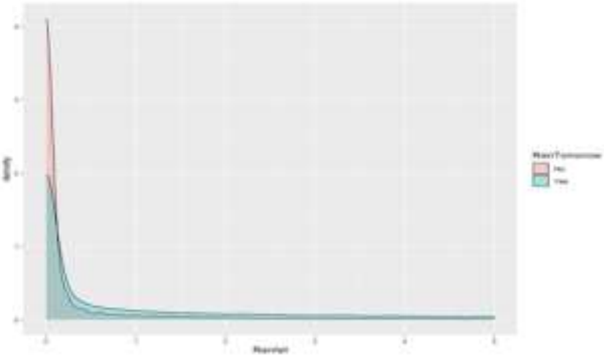
The results demonstrate that, despite the significant class imbalance, the random forest model excelled in predicting rainfall occurrence. It offers robust and balanced performance, which is vital in real-world applications where the cost of misclassifying rainy days can be high.

This study underscores the importance of evaluating models with suitable metrics that account for class distributions, particularly when dealing with imbalanced datasets. Metrics like recall and F1-score are more informative in such cases, and they guide model development and selection effectively.

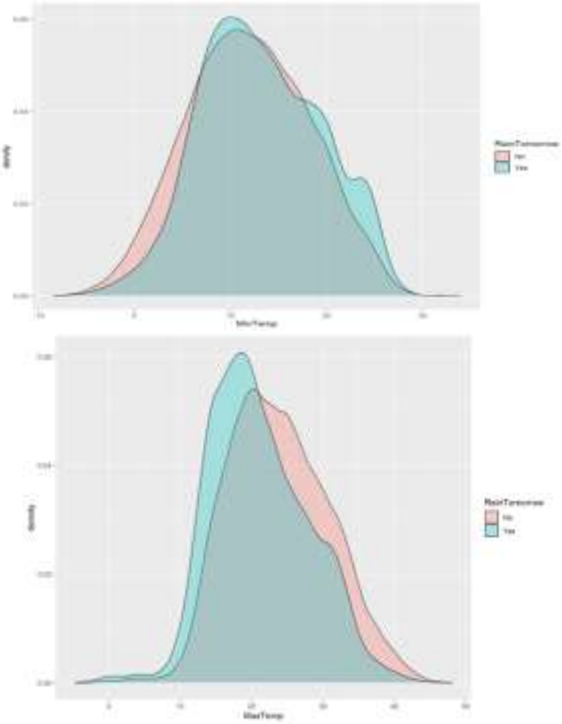
Furthermore, the ability to handle imbalanced data using metrics like the Gini index, in conjunction with techniques like over/undersampling and cost-sensitive learning, can further enhance model performance and make it more suitable for practical applications in which class imbalance is prevalent.

Data Visualization:

1. **Rainfall today:**



2. **Temperature & RainTomorow**



Confusion Matrix

```
> print(conf_matrix)
     y_pred
          1     2
  No  92246  1608
  Yes 27081   510
```

Accuracy

```
> TN <- conf_matrix[1]
> FN <- conf_matrix[2]
> FP <- conf_matrix[3]
> TP <- conf_matrix[4]
>
> accu_mod <- (TP + TN)*100 / (TP + TN + FN + FP)
> print(accu_mod)
[1] 76.37696
```

C. Blynk App Integration for Enhanced User Control

An additional level of user control and monitoring was added to the sun-tracking and protective covering systems with the integration of the Blynk app. Through the Blynk smartphone interface, users may now manually turn the protective covering on or off, giving them flexibility to adapt to changing weather conditions or personal operating preferences. The ability to regulate manually increases user flexibility and personalisation.The application also shows a light to users when the solar panel is actively producing power, giving them instant visual feedback on its operating state. The light turns off automatically in the case that severe rain triggers the system to shut off. This easily understood visual cue improves user awareness and reactivity, guaranteeing effective administration under a variety of environmental conditions.

VI. CONCLUSIONS

In conclusion, our sun-tracking solar panel technology prioritises durability and efficiency, marking a substantial leap in the solar energy generating industry. By using state-of-the-art elements like servo motors and Light-Dependent Resistor sensors, our system precisely tracks the passage of the sun throughout the day to maximise energy harvesting. By adding another line of defence, the synchronised shield increases the solar panels' resistance to different types of weather and lengthens their lifespan. Furthermore, our system displays proactive decision-making skills based on accurate weather forecasts by integrating real-time sensor input into a data science-driven rainfall prediction project. The random forest model's performance on the dedicated test set was impressive. It achieved an overall accuracy of 82.4%, showcasing its ability to make accurate predictions. More importantly, the model's recall, a crucial metric for identifying rainy days, reached 0.81, demonstrating its reliability in this aspect. In this code optimization, we successfully reduced the time complexity of calculating the Gini index The efficient and simplified formula for calculating the Gini index, as showcased in this study, provides a valuable tool for handling class imbalance in binary classification problems. By streamlining the process and eliminating the need to compute individual class probabilities and complements, it enhances the model development and selection process. This integration guarantees continuous energy generation by improving the system's resilience and adaptability to changing environmental conditions.The Blynk app's user interface provides simple visual cues for engagement and monitoring. To improve user awareness and engagement, users receive clear status updates, with the light signifying operating status and timely notifications for severe rain. All things considered, our solar panel system provides a dependable and easy-to-use means of producing clean, sustainable energy. Our initiative highlights the ongoing significance of solar energy in moving towards a cleaner future with its all-encompassing approach to environmental resilience and efficiency development. We're still dedicated to pushing the envelope in the development of reliable and strong solar technology, which will help accelerate the world's shift to renewable energy sources.

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