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Smart Dust Detection and Automation Cleaning of Photovoltaics Panel

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Abstract: The efficient operation of photovoltaic (PV) systems heavily relies on the cleanliness of their solar panels. Dust accumulation on PV panels can significantly reduce their power output and overall performance. The purpose of smart dust detection and automated cleaning of PV systems is to optimize their energy generation and maintenance. The system utilizes an array of low-cost dust sensors strategically placed across the PV panel array. These sensors continuously monitor the dust accumulation levels on individual panels and wirelessly transmit the data to a central control unit. The control unit employs advanced algorithms to analyze the sensor data and determine the optimal cleaning schedule based on predefined cleanliness thresholds. Upon detecting a significant dust accumulation on a particular panel, the control unit triggers the automation cleaning mechanism. The cleaning mechanism consists of an ESP32, two DC motors, a water pump, a relay, and a motor driver (L298N). The results demonstrated a significant improvement in the voltage output of the PV system after implementing the smart dust detection and automation cleaning approach. The system effectively reduced energy losses due to dust accumulation while minimizing manual intervention and maintenance costs. In conclusion, smart dust detection and automation cleaning systems offer an innovative solution for enhancing the efficiency and performance of PV systems. By automating the cleaning process based on real-time dust detection, the system optimizes energy generation and reduces the need for manual maintenance. This approach contributes to the sustainability and longevity of photovoltaic installations, enabling them to operate at their maximum potential while minimizing downtime and associated costs.

Keywords: Solar Panel, Solar Energy, Cleaning System, Panel, Monitoring

1. Introduction

The evolution of solar panels has led to increased efficiency and consumer interest in renewable energy. Variations in panel design, control, and management have contributed to this growth. However, environmental efficiency remains low, as the panel's output power determines the amount of irradiance

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reaching it [1]. After that, a solar photovoltaic system is a power system that uses sunlight to convert electricity into electricity. It includes solar panels, a charge controller, an inverter, a battery, and electrical accessories for efficient operation [2]. Next, photovoltaic modules' energy and efficiency are influenced by irradiance and spectral content of the sun. Maintenance is crucial for improving performance and irradiance by cleaning the surface of photovoltaic panels [3]. Dust accumulation hinders solar radiation and performance. Monitoring panel performance before and after cleaning ensures maximum solar radiation harvest. Lastly, the project aims to implement smart dust detection and automation cleaning in a photovoltaic system. The sensor detects dust particles and their reflected light, while the automation cleaning system uses various end-effectors to clean the surface. The system is powered by solar energy.

Many studies have confirmed that the reduction of solar photovoltaic energy production performance occurs when there is dirt and dust on the surface of the solar photovoltaic. Next, the process of cleaning system for the solar photovoltaic is still run manually which requires a specialist to operate the solar photovoltaic cleaning machine for the cleaning process of solar photovoltaic. In addition, the consumers have difficulty monitoring the data produced and the condition of the solar photovoltaic because of its location, which is usually on the roof. So, the dirt and dust must be cleaned because it has a significant impact on the performance of solar photovoltaics are determined by a variety of factors and must always be estimated or evaluated for individual circumstances. Therefore, a smart Internet of Things (IoT) photovoltaic system enhanced with dust detection and an automatic cleaning process will work as the main function to clean the surface solar photovoltaic according to the established program. Additionally, the installation Internet of Things (IoT) in the cleaning systems is to monitor the data produced by solar photovoltaics.

The project aims to design and develop a dust detection system for the solar photovoltaic panel. Then, an automated cleaning system was created on the solar photovoltaic panel. Finally, an IoT-based monitoring system was developed to monitor the Solar’s voltage and dust level.

2. Materials and Methods

2.1 Hardware of the project

Table 1 shows the project hardware components.

Table 1: Project hardware component

Hardware	Description
ESP32 Dev Module 	The ESP32 Dev Module is a versatile development board powered by the ESP32 microcontroller, offering dual-core processing, built-in Wi-Fi, Bluetooth, and a variety of GPIO pins for hardware interfacing. It's widely used in IoT and wireless communication projects due to its compact design and robust capabilities, making it a popular choice for both beginners and experienced developers.
Solar PV Panel 	A 10-watt solar panel with an output voltage of 18 volts is a compact photovoltaic device designed to convert sunlight into electrical energy. It's commonly used to charge small electronics, batteries, or power low-energy devices, providing a reliable and sustainable source of electricity in remote locations or off-grid setups.

Dust Sensor (GP2Y1010AU0F) 	The GP2Y1010AU0F Dust Sensor is a compact optical sensor designed to detect and measure the concentration of airborne dust particles. It operates on the principle of light scattering and is commonly used in air quality monitoring systems, allowing for real-time assessment of particulate pollution levels in various indoor and outdoor environments.
Water Pump 	The DC 12V 370 Water Pump is a compact and efficient pump designed for 12-volt DC power sources. It is commonly used in various applications, including aquariums, water fountains, and DIY projects, to circulate or transfer water efficiently, providing a reliable and compact solution for water pumping needs.
DC Motor and Wheel Set 	A DC Motor and Wheel Set typically includes a direct current (DC) motor and a wheel that can be easily attached to it. This set is commonly used in robotics and small-scale automation projects, enabling precise control over the movement and direction of a mobile platform when combined with appropriate motor control circuits.
Motor Driver Module (I298n) 	The I298n Motor Driver Module is an integrated circuit designed to control DC motors or stepper motors, often used in robotics and automation projects. It provides both direction and speed control, making it a versatile choice for motor control applications, and it can handle moderate to high current levels, making it suitable for a wide range of motor types and sizes.

2.2 Software development of the project

2.2.1 Fritzing software for circuit monitoring system

Figure 1 shows the proposed project consists of ESP32, LCD I2C, solar panel, and current sensor ACS712 20A. The solar panel generates voltage, while the current sensor reads and sends data to the microcontroller. The data is displayed on the LCD via I2C, and the ESP32 connects the hotspot to the smartphone using Blynk software.

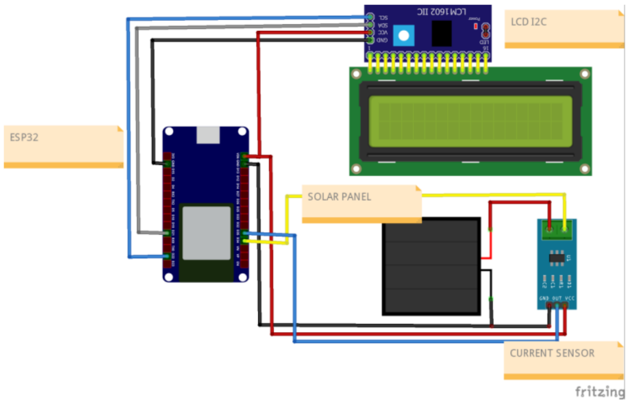

Figure 1: Proposed project monitoring system

2.2.2 Fritzing software for circuit dust detection and automated cleaning system

Figure 2 shows the proposed project consists of ESP32, a dust sensor (GP2Y1014AU0F), two DC motors, a motor driver (L298n), a relay, a water pump, and an adapter 12 V. The dust sensor detects dust density, and if it exceeds the set value, the water pump operates. The motor driver controls speed, direction, and rotation, while an adapter 12 V supplies the DC motor and water pump.

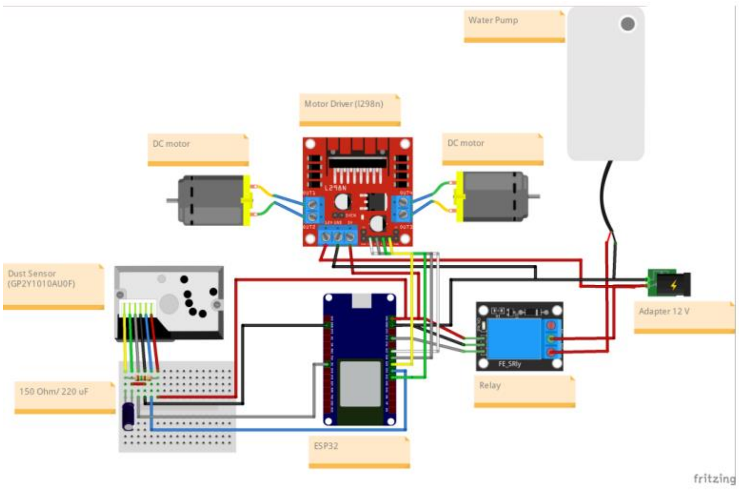

Figure 2: Proposed project dust detection and automated cleaning system

2.2.3 Arduino IDE for code of a project

The Arduino Software (IDE) includes a text editor, message box, terminal, toolbar, and menus for programming. It connects to Arduino hardware, enabling programming upload and communication. Figure 3 shows the Arduino IDE will be used for a dust detection and automated cleaning system, commanding components like the motor driver l298n to move the DC motor forward and reverse.

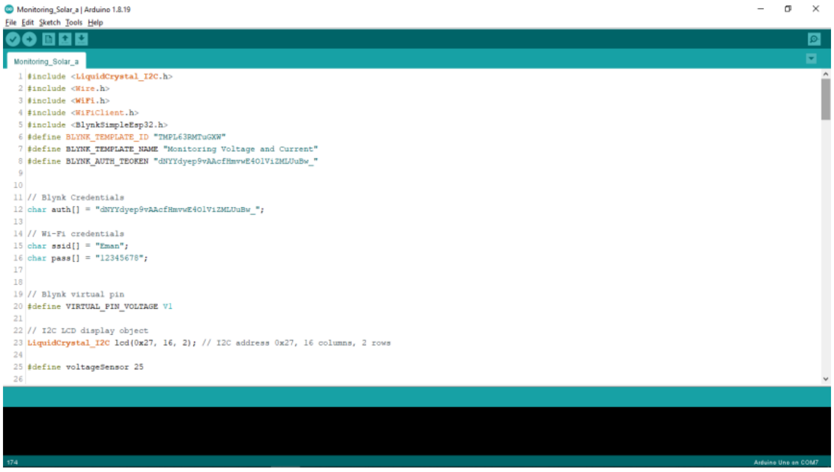

Figure 3: Code of the system in Arduino IDE software

2.2.4 Internet-of-Thing (IoT) system in Blynk software

Blynk is a software add-on for the Internet of Things, overseeing communication and data transfers between hardware, Blynk Cloud, and app projects. It supports remote hardware control and displays sensor data. Figure 4 shows that Blynk is used to monitor solar voltage using smartphones.

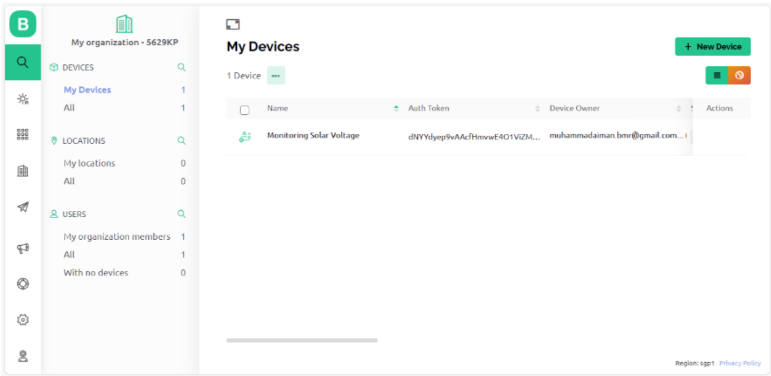

Figure 4: Interface Blynk monitor solar voltage

Figure 5 shows the flow of the project of the dust detection and automatic cleaning photovoltaic system. The dust sensor is the main component of the dust detection system, and it is used to detect dust levels on the surface of the solar photovoltaic panel. A microcontroller such as the ESP32 sends the data to the Blynk application to monitor the system. If the particle dust level is greater than or equal to 3.0 mg/m3, the cleaning process for the solar photovoltaic system will begin. The water pump will be activated as part of the cleaning system to pump water from the water tank through the hose water to the surface of the solar photovoltaic panel. After the cleaning process has finished, the DC motor will be turned on and used to move the wiper. Before that, the voltage value will be collected using a current sensor and displayed through LCD I2C. For the part monitoring system, the value of the measured voltage will be displayed the value on their smartphones. So, the user can monitor voltage readings through the smartphone.

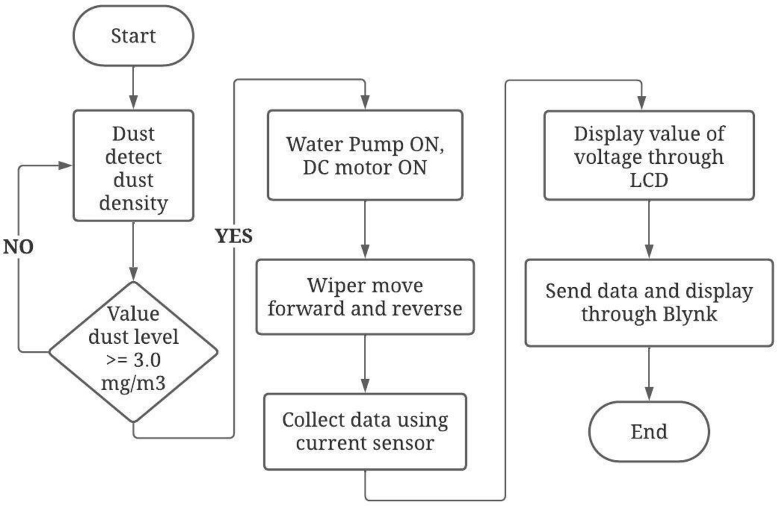

Figure 5: Flowchart process of the project

2.3 Equation of parameter

2.3.1 Determination Solar Voltage

The solar system produces the value of voltage and the value is used for monitoring system solar panel. The equation to calculate the value of solar voltage as stated [4]:

Relating Analog Digital Conversion (ADC) value to voltage:

$$\frac{Resolution\ of\ the\ ADC}{System\ Voltage} = \frac{ADC\ Reading}{Analog\ Voltage\ Measured} \qquad \text{Eq. 1}$$

Solar Voltage:

$$Solar\ Voltage, Vout = measure\ voltage \times (5.0 \times 1024)$$

2.3.2 Determination of Dust Density Level

The value of solar voltage before will be used for getting the value of dust density level. The equation to calculate the value of dust density level is stated as follow [5]:

Voltage value from the ADC value:

$$Voltage, Vout = measured\ voltage \times (5.0 \times 1024) \qquad \text{Eq. 2}$$

Amount dust particles (Chris Nafis equation)

$$Dust\ density = 170 \times voltage - 0.1$$

3. Results and Discussion

3.1 Monitoring system

Figure 6 shows the ESP32 is connected to Wi-Fi that is set up in the code by monitoring through the serial monitor and the LCD I2C displays the words for solar voltage with the value of it. After that, the smartphone that has Blynk software inside must connect with the same Wi-Fi connection. If the connection is successful, the serial monitor will print out the connection to Wi-Fi and the value of the solar voltage can be monitored using Blynk software. The word cleaning shows how the cleaning process is operated. Thus, the solar voltage can be monitored through LCD I2C and Blynk software. In addition, LCD I2C will also show all the processes that are ongoing on the solar panel.

Figure 6: Monitoring system

3.2 Dust Detection and Automation Cleaning System

Figure 7 shows the serial monitor recording the value of the dust density level and recording the process of the system flow. When the dust sensor detects a value above 3.0, the serial monitor will show the device, such as a water pump or DC motor, turning on and off according to the coding setup.

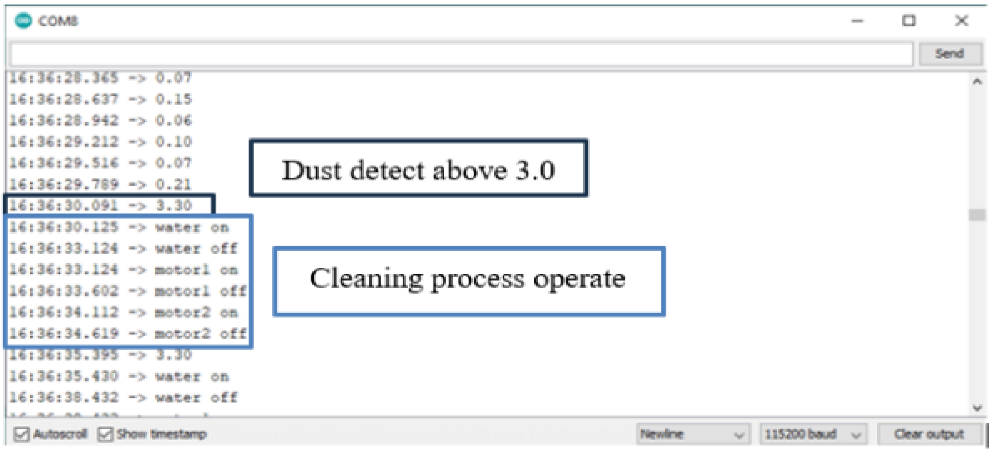

Figure 7: Dust detection and automation cleaning system

3.3 Blynk system

Figure 8 shows an interface of the Blynk application that can monitor solar voltage using a gauge meter. It is flexible and can be designed according to needs. This configuration needs to define the type of pin used which is analog, digital and virtual. In this project, a virtual v1 pin is assigned to collect the data from ESP32. The maximum value assigned to the gauge meter is 18 V. After that, it shows the Blynk timeline to record the history of usage of the Blynk software.

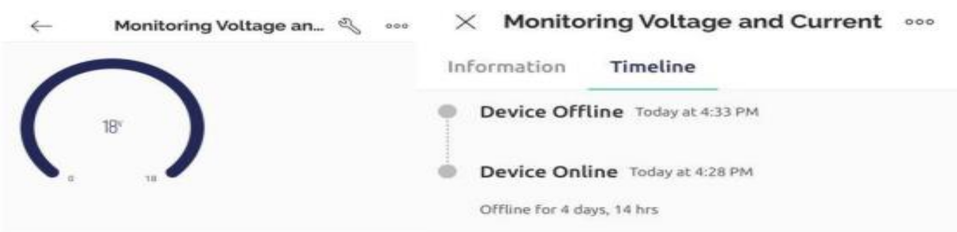

Figure 8: Interface of Blynk software

3.4 Condition solar photovoltaic panel before cleaning

Figure 9 shows the condition of a solar photovoltaic panel before undergoing any cleaning or maintenance. Solar panels, designed to convert sunlight into electricity, are exposed to the elements and can accumulate dirt and debris over time, diminishing their efficiency. Dirty or obstructed panels can hinder electricity generation. Hence, regular cleaning and maintenance are essential to ensure maximum efficiency and the consistent production of clean, renewable energy. Cleaning solar panels is a standard procedure to safeguard the long-term investment in solar energy systems and optimize energy output.

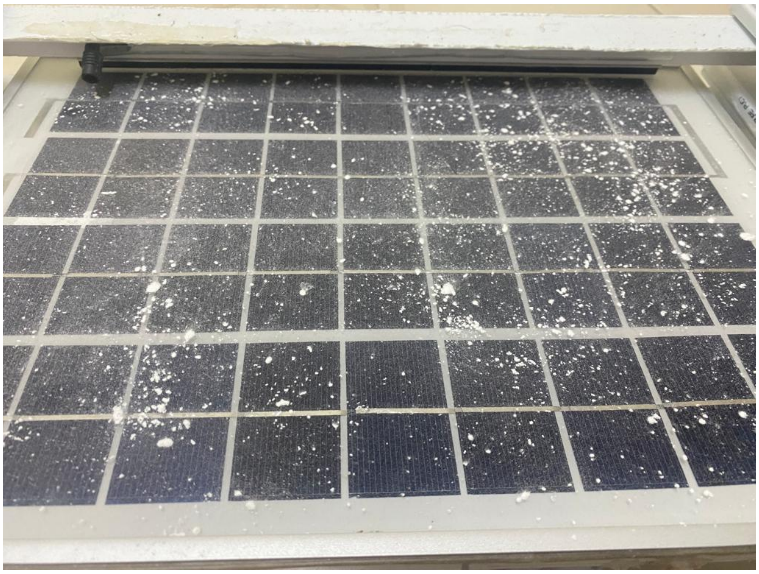

Figure 9: Surface solar photovoltaic panel before cleaning

Table 2 shows a clear pattern of electrical behavior over the course of a day. Starting at 8:00 AM, both voltage and current are relatively low, but they consistently increase, peaking at noon. Voltage reaches 12.15 volts, and current hits 0.60 amperes at this peak. In the early afternoon, voltage stabilizes at around 12.14 volts, while current decreases slightly to 0.58 amperes. Later in the day, both voltage and current gradually decline, with voltage at 11.39 volts and current at 0.33 amperes by 5:00 PM. This data suggests a time-dependent pattern that could be valuable for evaluating the performance and characteristics of the observed electrical system or device.

Table 2: Measured value before cleaning solar PV panel

Hours	Voltage (V)	Current (A)
0800	10.16	0.20
1000	11.19	0.29
1200	12.15	0.60
1300	12.14	0.58
1600	11.55	0.41
1700	11.39	0.33

3.5 Condition solar photovoltaic panel after cleaning

Figure 10 shows the condition of a solar photovoltaic panel after it has undergone a cleaning or maintenance procedure. Solar panels are exposed to outdoor elements and can accumulate dirt, dust, and debris over time, which can reduce their efficiency in converting sunlight into electricity. After cleaning, the solar panel's surface should be free from these contaminants, allowing it to operate at its optimal efficiency and generate the expected amount of clean and renewable energy. Cleaning solar panels is a routine practice to ensure their proper functioning and protect the long-term investment in solar energy systems.

Figure 10: Surface solar photovoltaic panel after cleaning

Table 3: Measured value after cleaning solar PV panel

Hours	Voltage (V)	Current (A)
0800	11.29	0.22
1000	12.43	0.32
1200	13.49	0.66
1300	13.48	0.64
1600	12.83	0.45
1700	12.65	0.36

Table 3 represents voltage and current measurements taken at different times during the day. Voltage started at 11.29 volts at 8:00 AM, increased to a peak of 13.49 volts at noon, remained stable around 13.48 volts in the early afternoon, and then gradually decreased. Current followed a similar pattern, starting at 0.22 amperes and peaking at 0.66 amperes at noon. This data reveals a daily electrical behavior pattern, potentially valuable for assessing the performance and characteristics of the related electrical system or device.

3.6 Prototype development

Figure 11 shows a prototype of a smart dust detection and automated cleaning system that was developed using an ESP32 microcontroller and embedded IoT through Blynk. The system includes a motor driver, two DC motors, a dust sensor, a water pump, a relay, and LCD I2C. All the components get the supply from ESP32 while the motor driver and water pump connected to 12 V adapter supply.

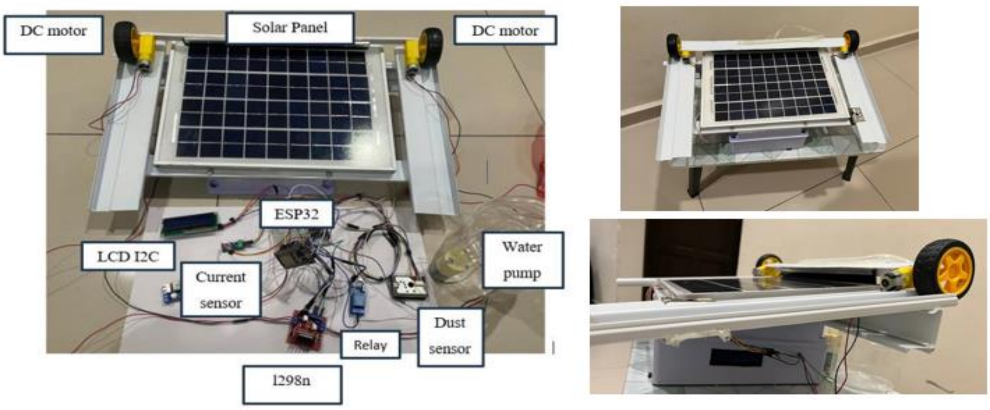

Figure 11: Prototype project

4. Conclusion

The development of smart dust detection and cleaning solar panel systems with the Internet of Things (IoT) has significantly improved power generation efficiency and solar panel durability. This technology addresses dust accumulation on solar panels, providing real-time monitoring and detection, leading to improved performance and efficiency of solar energy generation. The dust detection system offers numerous advantages, including proactive maintenance, cost savings, enhanced durability, and environmental sustainability. The automated cleaning system on solar panels provides numerous advantages, including cost-effectiveness, increased energy output, improved sustainability, and enhanced environmental benefits. The IoT-based monitoring system for solar panels, specifically monitoring solar voltage and dust levels, offers numerous advantages for solar energy installations, including real-time access to critical data, enhanced maintenance and troubleshooting, improved system efficiency and energy output, and cost savings. These technologies play a vital role in optimizing the performance and longevity of solar energy installations, facilitating the transition towards cleaner and more sustainable energy sources.

Acknowledgement

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