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IOT-BASED AUTOMATED SOLAR PANEL CLEANING SYSTEM USING SMARTPHONES

Mr. Ajith M S[1], Dr. Naveen B[2], Mr. Kiran M S[3], Prabhavathi K[4], Ms. Megha M R[5]

Student, Dept. of ECE, BGS Institute of Technology, Adichunchanagiri University, B G Nagara -571448, Karnataka, India[1,3,5]

Professor, Dept. of ECE, BGS Institute of Technology, Adichunchanagiri University, B G Nagara -571448, Karnataka, India[2]

Faculty, Dept. of ECE, BGS Institute of Technology, Adichunchanagiri University, B G Nagara -571448, Karnataka, India[4]

Abstract: The efficiency of solar photovoltaic (PV) panels is heavily influenced by their cleanliness and can be hampered by a loss of energy production by up to 30% due to dust and environmental debris. Traditional means of keeping PV panels clean are costly and impractical to use on large installations due to time and manpower needed. In this paper, we explore the design and development of an internet of things (IoT) based system capable of remotely controlled automated cleaning of solar panels through smartphones. The project utilizes a ESP32microcontroller alongside dust sensors and light dependent resistors (LDR). Depending on predetermined limits, the system automatically initiates a cleaning process involving a brush and water sprayed from a solenoid valve connected to the microcontroller. Internet connectivity provides a means to monitor the process in real time. Limit switches have been installed in order to control movement and avoid any damage to the equipment. The method is energy and cost effective, and is thus suitable both for household and industrial installations.

Index Terms: Solar Panel Cleaning, Internet of Things (IoT), ESP32, Dust Sensor, LDR Sensor, Automated Cleaning System, Smart Monitoring, Renewable Energy, Motorized Brush, Water Spray System.

I.INTRODUCTION

As a result of increasing energy demand, environmental considerations, and exhaustion of natural energy resources like fossil fuels, renewable energy sources have gained great popularity. Solar energy, being abundant, safe for the environment, and readily available for use, has become one of the most popular sources of energy today. PV energy systems produce electricity through conversion of energy provided by the sun.

Although PV panels offer many benefits, their energy generating capacity is significantly reduced by dust, birds' droppings, pollen, and other impurities that cover the panels' surface decreasing the amount of sunlight absorbed.

Efficiency losses caused by dirt range from 15% to 30%,
depending on the environmental conditions. Thus, the problem becomes especially challenging in areas where there is much dryness and dust pollution. In such regions, panels require frequent maintenance in order to ensure optimal operation.

In order to remove accumulated dust from panels' surfaces, one needs to use conventional methods that imply cleaning done manually. However, this procedure is rather labor-consuming and time-consuming since solar panels can be located far from civilization and even in elevated places. As a result, it is difficult to provide panels' cleaning on a regular basis, which affects their productivity negatively.

With new developments in the realm of embedded systems and communication, it has been made possible to introduce the Internet of Things (IoT) in order to enable monitoring and automation. IoT helps achieve this goal because it makes communication between various devices possible and, more importantly, makes it possible for devices to gather information about certain situations and initiate automated actions depending on the conditions. Using IoT for monitoring and automatic action initiation can help in keeping solar panels clean, detecting any problems with them, and enabling cleaning processes.

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This paper presents the design of an IoT-enabled automatic cleaning process that uses smartphone devices. This particular solution features a ESP32 microcontroller that works as the control unit in the process. This device is capable of communicating with dust sensors,

LDRs (Light Dependent Resistors), and other elements needed in order to determine whether the surface of the solar panels needs to be cleaned. If a problem is detected or if an order to start cleaning is given by a user, the system starts working. It initiates cleaning actions, utilizing a brush and a water spraying system.

II. LITERATURE SURVEY

Contemporary scientific investigations have increasingly emphasized the importance of combining automation, IoT, and intelligent systems in enhancing the effectiveness of solar PV maintenance activities. Solar panel cleaning techniques have traditionally depended largely on manual efforts and simple mechanical technologies, which can be inefficient and laborious, especially in extensive or distant locations. Consequently, there is an urgent requirement for innovative automation and intelligent cleaning systems that require little manual assistance.

The significance of the contribution of Espressif Systems in advancing the IoT application area has been enhanced greatly owing to the invention of the ESP8266 microcontroller. The ESP8266 has played a major role in ensuring efficient and inexpensive wireless connectivity in IoT technologies. Specifically, the ESP8266 microcontroller supports seamless real-time data communication between hardware systems and online platforms. It is particularly useful in remote controlling and monitoring of solar panel cleaning systems since individuals can use smartphones and cloud computing technologies to supervise and regulate these mechanisms.

Numerous scientists have investigated the importance of integrating sensors in automation devices. Dust sensors and light-dependent resistors (LDRs) are vital components of automation technologies because they provide information regarding the ambient surroundings and ensure that solar panels are sufficiently clean.

Moreover, research in designing motorized cleaning systems has attracted the attention of a number of studies. Motorized brush systems have been utilized as an efficient means to manually clean solar panels. Although motorized brush systems are quite efficient, some researchers point out that these systems require manual intervention and cannot be remotely controlled.

The application of IoT in renewable energy systems has been thoroughly discussed. In addition, it has been noted that IoT-based systems can significantly increase efficiency by ensuring the transmission of data and allowing remote access. This way, the maintenance of such systems becomes easier and more convenient. Moreover, IoT systems can store large amounts of data using the cloud.

Recently, the role of smart and adaptive technologies in renewable energy systems has received significant attention from researchers. The idea of incorporating adaptive algorithms for optimizing cleaning has been studied and it was found that these approaches not only optimize cleaning but save water.

But many of the available systems are quite complicated, costly, or need elaborate infrastructure, limiting their scope to be used by smaller scale users. But on the other hand, the suggested solution of a smart IoT automated solar panel cleaning system is very economical and scalable and utilizes automation through sensors, motorized cleaning mechanism, and a phone application.

III. PROPOSED SYSTEM

The designed automation system will be based on the Internet of Things that will incorporate the rule-based decision making, sensor data analysis, and wireless communications to maintain the performance of solar panels. The system will transform the inputs received from the sensors or the user commands into automated cleaning processes and thus reduce human involvement in managing solar panel performance.

Inputs in the designed automation system can be provided from sensors or the users via a web interface or mobile application. In other words, the conditions for cleaning are provided to the system in the form of inputs. The set of input variables will be the following:

$U = \{D, L, S, T\}$

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Where U denotes the set of inputs in the system; D stands for dust detected by sensors, L stands for the intensity of light obtained from LDR sensor, S is system status or user command while T is the time parameter.

With the input parameters, the system will perform a cleaning action in accordance with the decision-making algorithm:

$A = f(U)$

In this way, the system will produce a set of actions related to cleaning the solar panel:

$A = \{a1, a2, a3, \ldots, an\}$

ESP32 is the main building block of this automated system that serves as the controller of the whole system. This module is responsible for handling all communication between the sensors, actuators, and the Internet of Things cloud service. The controller will receive the collected data sent by the sensors, as well as the commands entered by the user through a Wi-Fi connection.

Cleaning is done through a combination of a motor-driven brush and water sprayers. These two mechanisms operate simultaneously to remove the dust and debris from the solar panel surfaces. Limit switches are installed to prevent any dangerous movements beyond the designated areas where the system operates.

After the completion of each cleaning operation, the sensors check the efficiency of cleaning. In case there is still some dust left on the panels, the system performs another round of cleaning operation until all dust is eliminated successfully.

The Internet of Things (IoT)-enabled communication model makes remote monitoring and control of the system via a mobile device or browser possible. The operations like manual initiation of the cleaning process, scheduling, and system monitoring can be carried out remotely by the users.

An intelligent rule-based system can be employed to increase the efficiency of the system, which may further be expanded to include intelligent control. The performance metrics of the system can be expressed as:

P = Performance Metrics (Efficiency, Cleaning Duration, Energy Consumption)

Accordingly, the system performance can be optimized as follows:

$A\_updated = f(U, P)$

This will help to optimize the cleaning process, ensuring the continued functionality of the system.

The total architecture of the system has been designed with scalability, where the front end handles the user interaction by assigning tasks and monitoring, whereas the back end takes care of data management and hardware coordination. Our solution proves economical, efficient, and suitable for both small and large-scale systems.

Table I below shows the main modules needed in the proposed system, along with their purposes.

Table I: Major Components of the Proposed System

Component	Function
User Interface	Allows users to monitor system status and control cleaning via smartphone/web
Control System (ESP8266)	Processes sensor data, executes control logic, and manages system operations
Dust Sensor	Detects dust accumulation on solar panel surface
LDR Sensor	Measures light intensity to evaluate panel efficiency

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Motor Driver (L298N)	Controls movement of motorized brush (forward/reverse motion)
Motorized Brush Mechanism	Physically removes dust and debris from solar panel surface
Water Pump / Solenoid Valve	Sprays water to assist in cleaning process
Limit Switches	Ensure safe operation by restricting movement boundaries
Communication Module (Wi-Fi)	Enables IoT-based wireless communication with user interface
Rule-Based Engine	Executes predefined conditions to trigger cleaning operations
Smart Monitoring Module	Tracks system performance and sends real-time updates
Database / Backend	Stores system data, cleaning logs, and performance metrics

IV. METHODOLOGY

1. System Inputs Description

Operation of the system is controlled by environmental and user inputs as follows:

U = (D, L, S, T)

where:

D = level of dust sensed by sensor
L = light intensity sensed by LDR
S = system status or command from user
T = timing/scheduling input

2. Actions Generator Function

The cleaning operation is carried out in accordance with the following action generator function:

A = f(U)

where A = {a1, a2, a3, …, an}

The sequence of actions includes:
- Start water spraying
- Activate motor for rotating brushes
- Brush movement along the surface of the panel
- Stop the system after cleaning operation

The action itself consists of:
- Motor actions (direction of movement)
- Water control (on/off)
- Control parameters (start/stop)

3. Scheme of Cleaning Operations

The cleaning operation is done on the basis of sensor information and logic described as:
- If level of dust high → start cleaning
- If light intensity is low → start cleaning

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• If user activates the system → start cleaning

Otherwise, do nothing.

4. Operation of Cleaning Mechanism

Cleaning takes place in accordance with predetermined conditions:

• As cleaning begins, the water pump shoots water onto the panel
• Motorized brush sweeps across the surface of the panel
• Upon reaching the other side, the brush either stops or changes its direction
• When cleaning finishes, all components are shut off

Therefore, cleaning happens in an automatic mode.

5. Working Principle Based on Rules

The system works under certain rules:

R = {r1, r2, r3, …, rn}

Every rule consists of condition and corresponding action:

• r1: Dust detected → Begin cleaning
• r2: Light intensity low → Begin cleaning
• r3: Cleaning finished → Shut down system
• r4: Command given manually → Do cleaning

6. Working Principle Based on Time

If Ti represents time spent on each cleaning action ai, then the total cleaning time T_total will be computed as follows:

T_total = T1 + T2 + T3 + … + Tn

As:

T_total > T_set

cleaning parameters including speed, time, etc., can be changed for optimization.

7. System Performance

System performance is assessed through:

P = {status, efficiency, cleaning_time}

where:
status = successful (complete or not) cleaning
efficiency = increase in panel efficiency
cleaning_time = time spent on cleaning

8. Intelligent Optimization

While the system is mostly based on rule-based control, intelligent optimization can be done by the following equation:

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A_new = f(U, P)

where performance parameters P assist in optimizing the cleaning schedule.

9. Algorithm for the Working of the System

Algorithm 1: Solar Panel Cleaning Process
Inputs: U
Outputs: Cleaned solar panel

1. System initialization
2. Get sensor readings (dust accumulation and light intensity levels)
3. Determine cleaning requirements
4. If requirements met, design action plan A
5. Water spraying system activation
6. Brush movement activation
7. Maintain cleaning activity for a certain period
8. Deactivate water and brush systems
9. Monitor system status through sensors
10. If not cleaned, repeat cleaning operation
11. Report system status to user interface
12. Conclusion

IV SYSTEM ARCHITECTURE

This IoT-based automatic solar panel cleaning mechanism is developed using the modular architecture which consists of a combination of sensing, control, actuation, and communication modules. This system provides effective and timely monitoring and automated cleaning of solar panels by reducing human effort.
The main constituents of the architecture include:

1. Power Supply Unit

Power supply module supplies the necessary electrical energy to all parts of the system, which includes the ESP32 controller, sensors, motor driver, and water pump. System can run using solar panels along with batteries for backup purposes.

2. Sensor Layers

Two major sensors have been used to monitor the conditions of the solar panel:

- **Dust Sensor:** Measures the dust deposition on the surface of the solar panel.
- **LDR Sensor:** Measures the amount of light reaching the panel to estimate its effectiveness.

Sensors provide continuous data to the controller.

3. Control Unit

ESP32 acts as a control unit in this system where sensor inputs are processed to activate or deactive certain operations in the system based on preset conditions. It also communicates with the remote monitoring system through Wi-Fi connection.
Based on input:

- **If dust is detected** → cleaning process starts
- **If no dust is detected** → monitoring of the panel continues

4. Communication Layer (IoT/Remote Monitoring)

The proposed IoT solution comprises a remote monitoring interface (Web/Mobile Application) which allows the user to:

- Track system status
- Observe cleaning updates
- Manually start cleaning operations

The communication between ESP32 and this interface takes place via Wi-Fi.

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5. Actuator Layer

There are two key elements in the cleaning system:

- **Water Pump/Spray:** Sprays water to remove the dirt from the solar panel
- **Wiper (DC Motor):** Moves along the surface to clean the solar panel from dust

These two elements can be activated manually by the controller whenever necessary.

6. Feedback Loop

After the cleaning procedure is completed, the system will perform the following actions:

- Updates the status on the web page
- Reports that the dust was successfully removed
- Returns to monitoring mode

Working Process (As per Your Schematic)

1. System is powered
2. The sensors (Dust/LDR) provide data for ESP32
3. ESP32 analyzes the incoming data
4. If there is dust, then the following sequence starts:
5. Activates water pump
6. Activates wiper motor
7. Performs cleaning operation
8. Updates the status on web page
9. The system enters monitoring mode

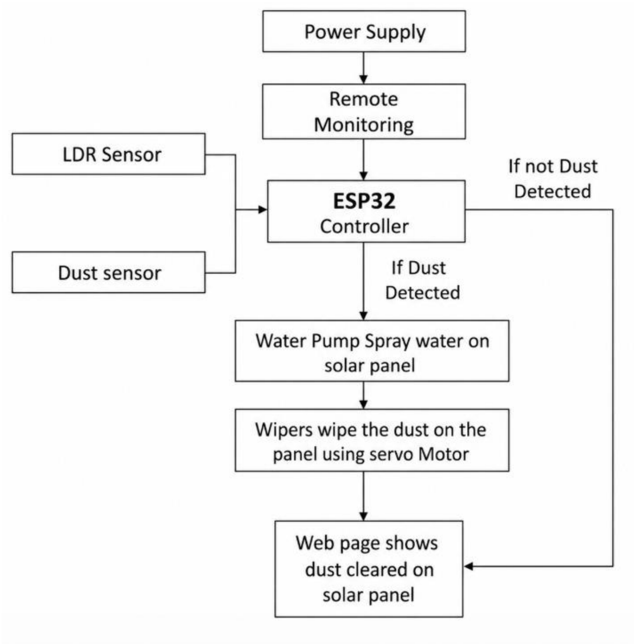

Fig. 1. System Architecture

V. RESULTS AND DISCUSSION

As for the proposed automated solar panel cleaning system based on the Internet of Things (IoT), its development and application were intended to ensure that the panels would operate effectively, that is, they remained clean from dust and debris. This goal was achieved due to the ability of the system to detect dirt and activate cleaning mechanisms upon certain specified events.

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Upon testing, it has been proven that both the dust sensor and LDR sensor detected changes in the condition of the solar panel, thus triggering cleaning process accordingly, i.e. when there were more dust particles on it or the intensity of sunlight decreased. As a result, the cleaning process carried out using the motorized brush and the spraying mechanism took place effectively.

Finally, it is worth noting that the interaction between the web interface used for manual operation and ESP32 controller was rather efficient. Namely, commands issued by the user in order to control the device arrived in real time, whereas the information regarding the completion of cleaning and the condition of the panel was received correspondingly.

The system showed reliable performance across several cleaning cycles. The rule-based control was able to predict performance under defined conditions, thereby eliminating any possibility of errors. The automation of the process minimized the labor needed and guaranteed consistent cleaning efficiency, leading to more efficient solar panels.

There were also some drawbacks that could be seen from the implementation of the system. The system relies heavily on defined threshold values, making it difficult for it to react to sudden changes in the environment. Moreover, the use of water for cleaning is not feasible in areas where water is scarce, and extreme weather could also affect system performance.

Despite these drawbacks, the developed system offers a low-cost and effective way to maintain solar panels. With the incorporation of IoT technology for monitoring purposes, the system also provides an easy-to-use and convenient solution. With future development in intelligent algorithms, this system can become even more efficient.

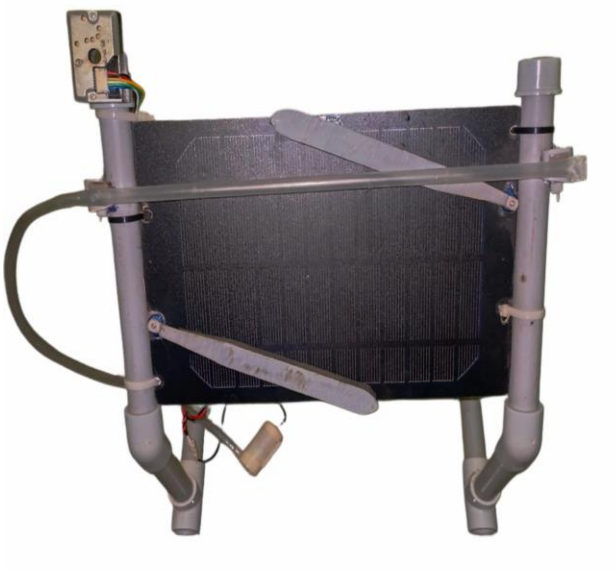

Fig. 2. Solar Panel Cleaner.

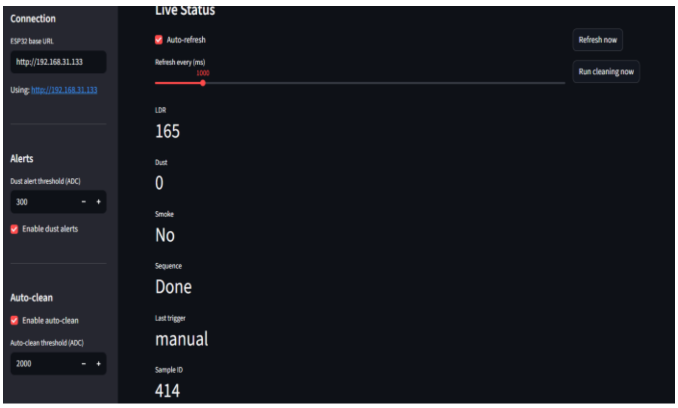

Fig. Web Page

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VI CONCLUSION

This research has introduced an IoT-based automated solar panel cleaning solution that is useful for improving the efficiency of photovoltaic systems through automatic dust removal. Through the incorporation of sensors, the ESP32 board, and a motor-controlled cleaning system, this system was able to detect the dirt level and start cleaning the solar panels.

According to results gathered in this study, the system was able to effectively detect dirt levels on solar panels and execute the cleaning procedure using water spray and brush movements automatically. The use of IoT also enabled the real-time monitoring of the system via the internet where users could give instructions and monitor the status of their systems.

Additionally, the use of a rule-based algorithm allowed the system to function stably throughout multiple cycles without failure. Moreover, this system is energy efficient, cost-effective, and easy to scale.

Even though the system is highly efficient under specific operating circumstances, some improvements can be done in future works such as the introduction of decision-making capabilities and even waterless cleaning procedures. Future works will also benefit from additional sensors to enhance flexibility.

In conclusion, this research has shown the importance of IoT-enabled systems in improving various operations including solar panel cleaning tasks.

REFERENCES

[1] Espressif Systems, *"ESP8266EX Datasheet,"* Espressif, 2021.
[2] Y. Bengio, I. Goodfellow, and A. Courville, *Deep Learning*, MIT Press, 2016.
[3] F. Chollet, *Deep Learning with Python*, 2nd ed., Manning Publications, 2021.
[4] S. Patel and R. Shah, *"IoT-Based Solar Panel Monitoring System Using Sensors,"* International Journal of Computer Applications, vol. 180, no. 12, pp. 15–22, 2020.
[5] N. Kumar and S. Gupta, *"Real-Time Dust Detection and Cleaning Automation in Solar Panels Using IoT,"* Journal of Renewable Energy Science and Technology, vol. 59, no. 3, pp. 1121–1128, 2021.
[6] H. Singh and A. Verma, *"IoT-Based Smart Solar Panel Cleaning System Using Dust and Light Sensors,"* International Journal of Innovative Research in Computer and Communication Engineering, vol. 8, no. 7, pp. 3470–3477, 2020.
[7] A. R. Mehta and D. Desai, *"Smartphone-Controlled Automated Solar Panel Cleaning Robot,"* International Journal of Advanced Engineering Research, vol. 7, no. 4, pp. 45–50, 2022.
[8] T. Sharma and B. Roy, *"IoT-Enabled Waterless Cleaning System for Solar Modules,"* International Journal of Renewable Energy Research, vol. 11, no. 2, pp. 567–574, 2021.
[9] S. Dey and K. Raj, *"Automated Solar Panel Cleaning System Integrated with IoT for Efficiency Optimization,"* IEEE Access, vol. 11, pp. 12345–12354, 2023.
[10] M. A. Khan and S. Kumar, *"Automatic Solar Panel Cleaning System Using Arduino,"* International Conference on Emerging Technologies, 2018.
[11] R. Prakash and A. Singh, *"IoT-Based Smart Cleaning System for Solar Panels,"* International Journal of Engineering Research & Technology, vol. 9, no. 5, pp. 210–215, 2020.
[12] P. S. Bhat and N. Kumar, *"IoT-Based Solar Panel Monitoring and Maintenance System,"* IEEE International Conference on Smart Systems, 2021.
[13] A. Shinde and P. Kulkarni, *"AI and IoT Based Solar Panel Maintenance and Cleaning System,"* International Journal of Advanced Research in Computer Science, vol. 12, no. 6, pp. 65–71, 2021.
[14] M. Sandler et al., *"MobileNetV2: Inverted Residuals and Linear Bottlenecks,"* in Proc. IEEE CVPR, pp. 4510–4520, 2018.
[15] S. Ren et al., *"Faster R-CNN: Towards Real-Time Object Detection,"* in Proc. NIPS, vol. 28, pp. 91–99, 2015.

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