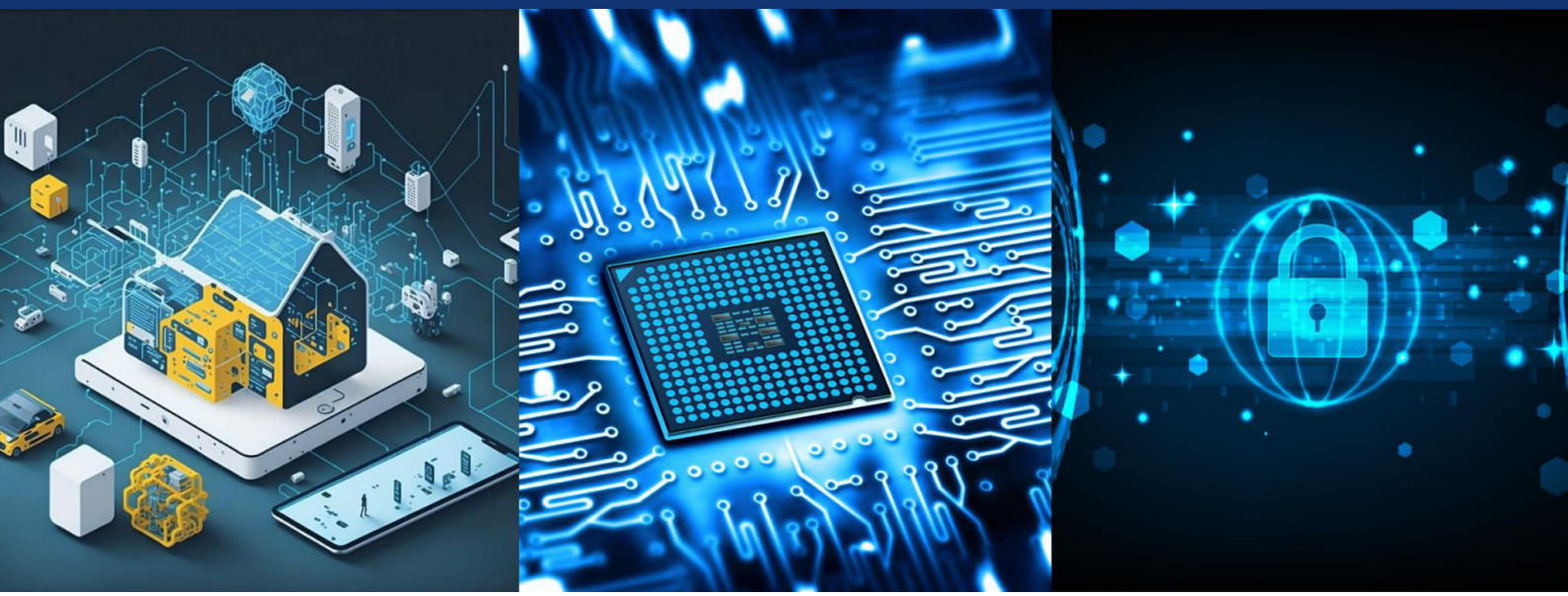
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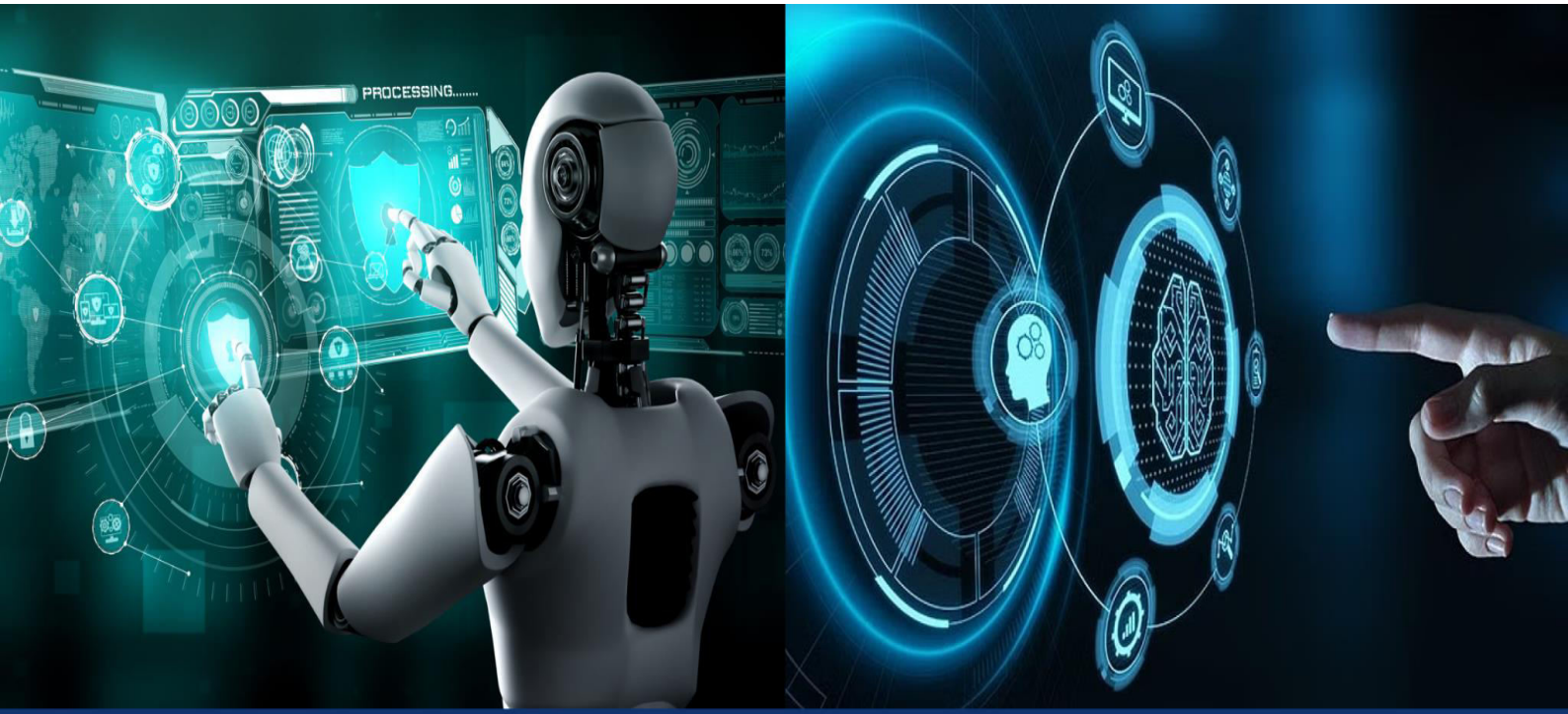
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Sensor-Feedback Dust Removal and Remote Performance Tracking for Solar PV Panels Using Arduino and NodeMCU

V. Ponniyinselvan[1], G. Sabari[2], S. Perarasu[3], M. Sanjayraj[4], M. Velmurugan[5]

Professor, Department of Electronics and Communication Engineering, Mahendra College of Engineering, Salem, Tamil Nadu, India[1]

UG Students, Department of Electronics and Communication Engineering, Mahendra College of Engineering, Salem, Tamil Nadu, India[2,3,4,5]

ABSTRACT: Dust accumulation lowers the output of solar photovoltaic (PV) panels, and manual cleaning is laborious. This paper presents an IoT-based system in which voltage and current sensors and an Arduino calculate panel power, a motor-driven brush removes dust, and a NodeMCU sends readings to a web dashboard. Rain, temperature and humidity sensing avoids unnecessary cleaning. The dashboard stored 766 records, showing about 12.12 V and 1.45 to 1.47 A (17.6 to 17.8 W) under clear, dry conditions. The system supports low-cost remote monitoring and maintenance.

KEYWORDS: Solar Panel; Internet of Things (IoT); Voltage and Current Sensors; Arduino; Automatic Cleaning

I. INTRODUCTION

Solar photovoltaic (PV) systems are widely used for generating clean and renewable electrical energy. The performance of a solar panel depends mainly on the amount of sunlight received by its surface. However, the accumulation of dust, dirt, sand, bird droppings, leaves, and other environmental contaminants on the panel can reduce the amount of sunlight reaching the solar cells. This results in a decrease in the output voltage, current, and overall power generation of the solar panel. Regular cleaning is therefore necessary to maintain the efficiency of a solar PV system.

Conventional solar panel cleaning is generally performed manually at regular intervals. This method requires additional labor, time, and maintenance effort, and it may not be suitable for large-scale solar installations. Cleaning the panel unnecessarily can also waste water and energy. Therefore, an automated cleaning system can provide a more efficient and convenient solution by operating the cleaning mechanism when required.

The proposed Solar Panel Cleaning and Maintenance System with Current and Voltage Sensors combines automatic panel cleaning with continuous electrical performance monitoring. A voltage sensor measures the output voltage of the solar panel, while a current sensor measures the generated current. Using these measurements, the controller calculates the output power of the panel. A microcontroller monitors these values and controls a motorized cleaning mechanism such as a rotating brush or wiper.

The system can compare the electrical output before and after cleaning to determine whether panel performance has improved. A significant reduction in voltage, current, or power can be used as an indication that cleaning or maintenance may be required. This approach provides both automatic cleaning and condition-based maintenance, reducing manual intervention while helping maintain efficient solar energy generation.

II. LITERATURE SURVEY

Dust and other soiling deposits are a well-documented cause of reduced PV output. Mani and Pillai [2] reviewed the impact of dust on PV performance, and Rao et al. [3] studied how dust deposition influences panel performance.

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Alshareef [6] reviewed the effects of soiling on PV module performance, while Ilse et al. [4] assessed soiling losses and mitigation strategies from a techno-economic point of view. Reviews of dust mitigation and removal methods are given in [5] and [7]. Module temperature also affects PV efficiency, as discussed in [8] and [9], which is why temperature and humidity are recorded in this work.

The Internet of Things (IoT) is widely used for remote monitoring. Gubbi et al. [1] described the architectural elements and future directions of IoT, and Atzori et al. [10] surveyed IoT technologies. Shah et al. [11] presented an IoT-based system that combines panel tracking, cleaning and output monitoring using an Arduino Uno, a Wi-Fi module and a mobile phone, and Olanrele et al. [13] built an IoT-based weather station using an embedded system. Begum et al. [12] combined dual-axis solar tracking with weather monitoring and an automated cleaning mechanism that is activated by weather conditions such as rain or dust.

In contrast, the system proposed here concentrates on a fixed panel with motor-driven cleaning and records the voltage, current, power, rain, humidity and temperature readings together with the cleaning status and stage in a web dashboard, using a low-cost prototype built around an Arduino and a NodeMCU.

III. METHODOLOGY / APPROACH

A. System Overview

The proposed IoT-Based Solar Panel Cleaning and Maintenance System with Current and Voltage Sensors combines automatic cleaning with real-time monitoring of solar-panel performance. A microcontroller controls the complete system, while a voltage sensor and current sensor continuously measure the electrical output of the solar panel. The controller uses these measurements to calculate the generated power and identify changes in panel performance. A motorized brush or wiper mechanism is used to remove dust and dirt from the panel surface. When cleaning is required, the controller activates the motor and moves the cleaning mechanism across the panel. After cleaning, the system measures the voltage and current again to compare the power output before and after cleaning. An IoT module such as ESP32/NodeMCU sends the measured voltage, current, power, and system status to a cloud or IoT monitoring platform through the internet. The user can remotely monitor the solar panel condition using a mobile phone or web dashboard. If the output power decreases below a predefined level, the system can provide a maintenance or cleaning indication. Thus, the proposed system reduces manual effort, enables remote monitoring, and provides an automated, low-cost, and efficient solution for solar-panel cleaning and maintenance.

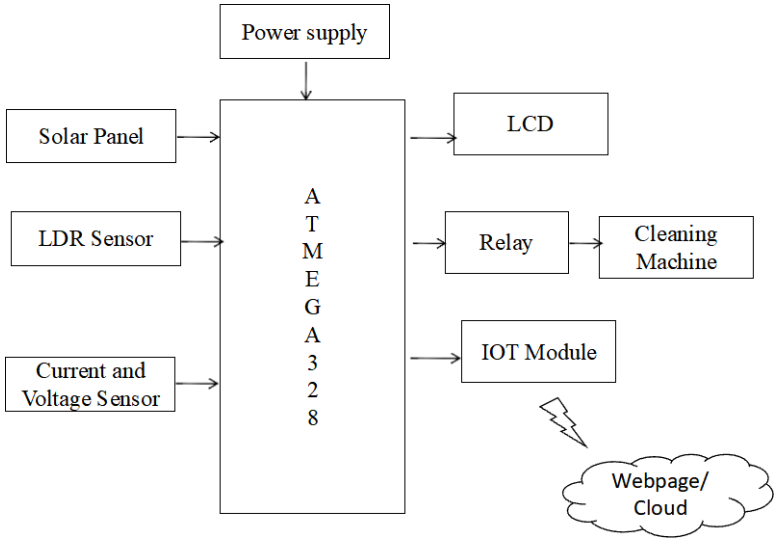


Fig. 1. Block diagram of the proposed system

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B. Hardware Description

1) Solar Panel



Fig. 2. Solar Panel

A solar panel is an assembly of photovoltaic cells mounted in a rectangular frame. It converts sunlight directly into direct current (DC) electricity. Several panels connected together form a PV array, which can supply loads directly or, through an inverter, feed power into the alternating current (AC) grid.

2) Arduino Uno R3 Microcontroller

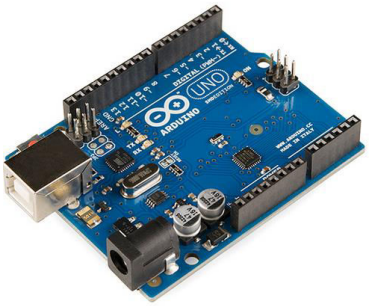


Fig. 3. Arduino Board

The Arduino Uno R3 is a development board built around the ATmega328 microcontroller. It provides 14 digital input/output pins, six of which can produce PWM output, six analog inputs, a 16 MHz clock, a USB port, a power jack, an ICSP header and a reset button. In this system it reads the sensors, calculates the panel power and controls the cleaning motor. The board can be powered through USB, an adapter or a battery.

3) LCD Display



Fig. 4. LCD

The LCD module is a character display that shows letters and numbers, so that readings and system status can be seen on the prototype itself. It is driven by the microcontroller through its data and control lines.

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4) Power Supply

The power supply takes the AC mains input through a 12 V step-down transformer. A diode rectifies the AC into DC, and a capacitor smooths the rectified voltage.

5) Node MCU



Fig. 5. Node MCU

NodeMCU is an open-source IoT development board based on the ESP8266 Wi-Fi chip, with firmware that is programmed in Lua. It has on-board memory and firmware to manage the connected devices. In this system it sends the measured voltage, current, power and status to the web dashboard over Wi-Fi.

6) Current Sensor



Fig. 6. Current Sensor

A current sensor measures the electric current flowing in a conductor and converts it into a signal that the microcontroller can read. Common sensing techniques use shunt resistors, coils or transformers, and the choice depends on the current range, size, cost, safety, accuracy and reliability. Here the sensor measures the current generated by the solar panel.

7) Voltage Sensor



Fig. 7. Voltage Sensor

A voltage sensor measures the voltage of a circuit and gives the microcontroller a proportional signal, typically by scaling the voltage down to the range of the analog input. Such modules are compact, safe to use and accurate. Here the sensor measures the output voltage of the solar panel.

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8) DHT11 Sensor

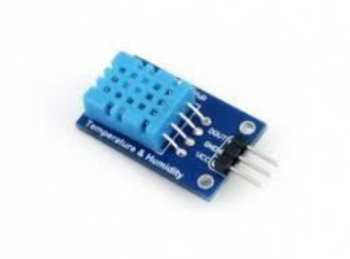


Fig. 8. DHT11 Sensor

The DHT11 is a low-cost digital sensor that measures both ambient temperature and relative humidity. It combines a capacitive humidity element with a thermistor and sends the readings to the microcontroller as a digital signal. In this system the readings help to interpret the panel behaviour, since temperature affects PV efficiency [8], [9].

9) Rain Drop Sensor

The rain drop sensor is used in the solar panel cleaning and maintenance system to detect rainfall. It works by sensing changes in electrical conductivity when rainwater falls on its sensing surface. When rain is detected, the sensor sends a signal to the controller, which can stop or postpone the cleaning motor to avoid unnecessary operation. After the rain stops, the controller can check the solar panel's current and voltage readings to determine whether cleaning is required. This sensor helps reduce unnecessary motor operation, save energy, and improve the efficiency of automatic solar panel cleaning and maintenance.

C. Prototype

Fig. 9 shows the prototype kit assembled from the components described above.

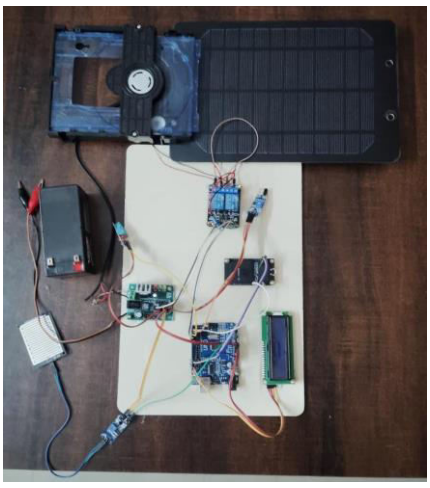


Fig. 9. Project kit

IV. RESULTS & DISCUSSION

A. Data Logging and Dashboard

The sensor readings are collected by the Arduino and forwarded by the NodeMCU as text messages to a web dashboard, which stores them as records. Table I summarises the dashboard on 27 October 2026. It held 766 records in total, logged on 21 and 22 October 2026 at roughly 50 and 710 records respectively (read from the activity chart). The 725 Active and 41 Processed labels describe how the dashboard handles the stored messages and do not describe the condition of the solar panel.

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TABLE I. DASHBOARD SUMMARY

Parameter	Value
Total records stored	766
Records recorded on 27-10-2026	0
Records with status Active	725
Records with status Processed	41
Records logged on 21-10-2026 (approx.)	50
Records logged on 22-10-2026 (approx.)	710

B. Recorded Readings

Each stored record contains the solar voltage, current, temperature, humidity, IR dust status, rain analog value, rain status, cleaning status and cleaning stage. Table II lists the first three records, with the power calculated from the logged voltage and current as $P = V \times I$.

TABLE II. SAMPLE RECORDS STORED BY THE DASHBOARD

Parameter	Record 1	Record 2	Record 3
Date	22-10-2026	22-10-2026	22-10-2026
Solar voltage (V)	12.12	12.12	12.12
Current (A)	1.453	1.467	1.452
Power, P = V × I (W)	17.61	17.78	17.60
Temperature (°C)	30.00	30.00	30.00
Humidity (%)	80.00	80.00	80.00
IR dust status	CLEAR	CLEAR	CLEAR
Rain analog value	1023	1023	1023
Rain status	NO RAIN	NO RAIN	NO RAIN
Cleaning status	STOPPED	STOPPED	STOPPED
Cleaning stage	0	0	0
Record status	Processed	Active	Active

Note: record 2 holds the same reading twice, stored as two consecutive messages in one record.

C. Discussion

In all three records the voltage is 12.12 V and the current stays within about 1% (1.452 to 1.467 A), giving a calculated power of 17.60 to 17.78 W. The IR dust status is CLEAR, the rain sensor reads 1023 with status NO RAIN, and the cleaning status is STOPPED at stage 0, so the controller correctly kept the motor idle on a clean, dry panel. The records show that the complete chain of sensing, calculation, wireless transfer and dashboard storage works and that every reading is logged together with the cleaning decision. The dashboard follows the same idea as the IoT systems in [11] to [13], which give remote visibility of electrical and environmental readings. In this prototype each record also stores the cleaning status and stage next to the electrical and weather readings, which links the panel output to the cleaning mechanism.

The records shown were captured with a clean panel and no cleaning cycle, so they do not yet show the power recovered by cleaning. The dashboard also holds no records for 27 October 2026, the day it was captured. A test with a deliberately soiled panel, recording power before and after each cleaning cycle, is needed to measure the cleaning effectiveness.

V. CONCLUSION

The proposed IoT-Based Solar Panel Cleaning and Maintenance System with Current and Voltage Sensors provides an efficient method for automatic cleaning and real-time monitoring of solar panel performance. The cleaning mechanism removes accumulated dust and dirt, while the current and voltage sensors measure the electrical output of the panel. An IoT module sends the measured voltage, current, and power data to an online monitoring platform, allowing the user to

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view the panel status remotely. The system can compare the power output before and after cleaning to evaluate cleaning effectiveness and identify possible maintenance requirements. Overall, the proposed system reduces manual effort, improves monitoring, and provides a low-cost and practical IoT-based solution for solar panel maintenance and performance monitoring.

The dashboard stored 766 records of voltage, current, temperature, humidity, dust, rain and cleaning status, with stable readings of about 12.12 V and 1.45 to 1.47 A on a clean, dry panel. The work can be extended with tests on a deliberately soiled panel, a maximum power point tracking (MPPT) charge controller, machine learning on the stored data to predict dust build-up, dual-axis solar tracking [12] and dust-repellent coatings [4]. Secure communication and extra sensors for wind speed and dust density can improve the data, and the single-panel kit can be extended to a field of panels by adding more sensing nodes.

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