IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 5, June 2025
Impact Factor: 7.67

IOT-Based Solar Panel Cleaning and Monitoring System

Shwet Mahale[1], Pratik Mali [2], Pravin Shivane[3], Prof. Bhagyashri Sherkhane[4]
Students, Department of EEE[1,2,3]
Guide, Department of Electrical Engineering[4]
Zeal College of Engineering and Research, Narhe, Pune, Maharashtra, India

Abstract: *This paper presents an "IoT-based system for cleaning and monitoring solar panels" to maintain their optimal performance. Dust and debris accumulation reduces the efficiency of solar panels. The proposed system uses sensors to detect soiling and environmental conditions such as sunlight intensity, temperature, and humidity. When soiling exceeds a threshold, a water pump is activated automatically to clean the panel. The system is based on a microcontroller integrated with ESP8266 Wi-Fi for real-time data monitoring. The collected data is sent to a cloud platform for performance tracking. This system minimizes human intervention, reduces maintenance cost, and improves solar energy output..*

Keywords: Solar Panel, IoT, Cleaning Mechanism, Microcontroller, Sensors, Efficiency, ESP8266, Automation

I. INTRODUCTION

Solar panels are a reliable and eco-friendly source of energy, but their efficiency is greatly influenced by environmental factors, particularly the accumulation of dust and debris. Manual cleaning is inefficient and costly, especially in remote locations. This paper introduces an automated IoT-based solar panel cleaning and monitoring system to optimize energy yield.

II. LITERATURE REVIEW

The efficiency of solar photovoltaic (PV) systems is significantly affected by the accumulation of dust, dirt, and environmental pollutants on panel surfaces. Numerous studies have addressed methods to enhance the performance and longevity of solar panels, primarily focusing on automated cleaning techniques and real-time performance monitoring using Internet of Things (IoT) technologies.

According to Mani and Pillai (2010), dust accumulation can reduce solar panel efficiency by up to 20–50% in arid regions, making cleaning an essential maintenance task [1]. Traditional cleaning methods are often labor- intensive, water-consuming, and non-scalable. To address this, researchers have proposed automatic or semi- automatic cleaning systems. For instance, Hussain et al. (2021) developed an automated solar panel cleaning mechanism using rotating brushes, achieving a notable increase in energy output after cleaning [2].

With the advent of IoT, researchers have further integrated sensor networks and wireless technologies for performance monitoring. Shaikh et al. (2017) demonstrated the potential of IoT in solar energy systems by employing sensors to collect data such as temperature, irradiance, and voltage, which were transmitted to a cloud server for remote monitoring [3]. This system enabled predictive maintenance and efficiency tracking, reducing system downtime.

A combined approach of IoT-based cleaning and monitoring was proposed by Kale et al. (2020), where a dual system comprising motorized wipers and sensor modules was controlled through a microcontroller and IoT platform [4]. Their results indicated improved panel cleanliness and enhanced energy production with real-time alerts sent to the user via mobile applications.

Another relevant work by Majeed et al. (2019) involved the use of NodeMCU with cloud integration to develop a real-time solar monitoring system. The study emphasized the cost-effectiveness and scalability of using open- source IoT components like Arduino and Blynk [5]. Similarly, Raza et al. (2021) explored smart monitoring systems using wireless sensor networks, highlighting the importance of data analytics in detecting system faults and scheduling cleaning operations optimally [6].

Most recent advancements include hybrid cleaning systems integrating robotic arms and electrostatic dust removal mechanisms, managed through IoT dashboards (Patel et al., 2022) [7]. These systems are particularly suitable for large-scale solar farms in dusty environments, offering autonomous operation with minimal human intervention.

Despite the technological progress, challenges such as power consumption of the cleaning units, sensor calibration, environmental adaptability, and initial installation costs remain areas of ongoing research. The literature consistently underscores the need for sustainable, low-maintenance, and intelligent systems to ensure optimal solar energy harvest.

III. SYSTEM DESIGN AND METHODOLOGY

The proposed IoT-based solar panel cleaning and monitoring system is designed to enhance the performance of solar panels by automating the cleaning process and enabling real-time monitoring. The system architecture integrates various hardware and software components to achieve a self-sustained, remotely controllable energy optimization solution.

At the heart of the system lies an ATmega328 microcontroller, which acts as the central processing unit. It gathers input from various sensors, makes logical decisions based on programmed thresholds, and controls the operation of the cleaning mechanism. The solar panel is connected to a Li-Ion rechargeable battery via a charge controller to store generated electricity, which is then used to power the system components.

The system continuously monitors key environmental and performance parameters such as light intensity, voltage, current, temperature, and humidity using the following sensors: LDR (Light Dependent Resistor) to detect light intensity and infer dust accumulation levels, INA219 sensor for accurate voltage and current measurement, DHT11 sensor to measure temperature and humidity for performance analysis and predictive maintenance.

The cleaning mechanism involves a mini submersible water pump, which is activated via a relay module controlled by the microcontroller. When dust levels (as inferred from reduced light and output voltage) cross a certain threshold, the pump draws water from a reservoir and sprays it onto the panel. This ensures automatic and timely cleaning without manual intervention.

For communication and remote monitoring, the system uses the ESP8266 Wi-Fi module, which transmits collected data to a cloud server. Users can access real-time system status through an IoT dashboard, and the data can also be used for historical analysis and maintenance planning. A 16x2 LCD display is included to show on-site values such as voltage, current, and cleaning status.

• Solar Panel – Generates electricity and provides input voltage to the system.
• Battery – Stores energy and powers the control circuit.
• Microcontroller (ATmega328) – Reads data from sensors and makes cleaning decisions.
• Sensors (INA219, DHT11, LDR) – Provide real- time feedback on environmental and panel conditions.
• Relay Module – Acts as a switch for the water pump.
• Water Pump – Responsible for the physical cleaning of the solar panel.
• ESP8266 Module – Sends data to a cloud server via Wi-Fi for IoT integration. • LCD Display – Shows system output values for local monitoring.

The circuit diagram shows the interconnection between the microcontroller, sensors, power supply, relay, pump, and communication module. The power supply unit provides 12V DC for motor operations and is stepped down to 5V using the LM7805 voltage regulator for logic circuits. The sensors feed analog/digital signals to the microcontroller, which then actuates the cleaning mechanism if performance drops due to panel soiling. The entire circuit is designed for low power consumption and high efficiency.

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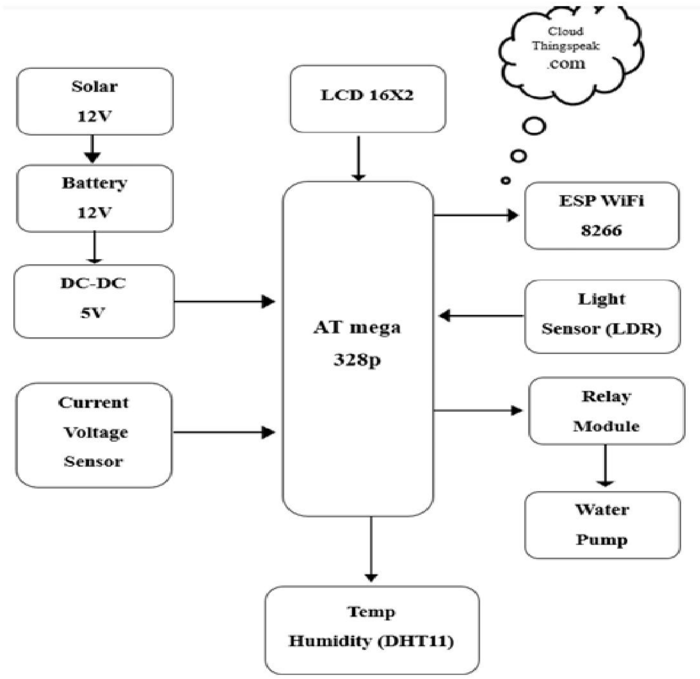


Fig.1. Block Diagram of IoT based solar panel cleaning and monitoring system

IV. HARDWARE COMPONENTS AND FUNCTIONALITY

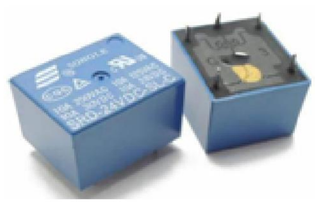
Microcontroller : It will control the whole system. µC will control various blocks of this paper i.e. Spray Mechanism, Motor and Spray Valve Control etc. As per the coding we can control these blocks. For coding it requires a C programming.

ESP8266 Wi-Fi module : ESP8266 Wi-Fi module is used in this work to integrate different components connected via various sensors and devices to have a robust network. It has voltage regulators, USB to serial converters, numerous input/output pins, etc. It can accommodate diverse ranges of sensors readily and supports the Arduino IDE platform to write programming languages for it.

Li-Ion Rechargeable Battery : Lithium-ion (Li-ion) rechargeable battery is used in this work because it is very ecofriendly, possesses very high energy density, and lower rates of self-discharge. During the discharging and recharging cycles, it undergoes movement of charged particles through cathodes and anodes to create current flow.

Solar Panel : In this work, a mono crystalline mini solar panel was used having a battery capacity of up to 200mAhat 6 V to test our designed system's functionality. The panel converts light radiation from the sun into usable electricity.

Relay Module : Controlling any device driven by high voltage and current requires low voltage and current signals. In such cases, the relay module is highly effective. It works like an electrical switch that opens or closes mechanical or magnetic circuits to regulate electricity flow at high voltage and high current. A control circuit processes the control signals to activate relays.



Water Pump : A mini submersible DC motor pump was used in this work to lift water from the underground reservoir during the solar panel cleaning process. This type of small-sized and robust pump consumes very low power at high efficiency and can pump water without priming.

Liquid Crystal Display (LCD): Here we used LCD to display the current state of the paper. Size of LCD is available from 8x2 to 40x4. For this paper we have used 16x2 LCD. 16x2 represents the rows and columns i.e. 16 columns and 2 rows.

LDR Sensor : The Light-Dependent Resistor (LDR) sensor, which changes its resistance based on the light intensity on its surface, is used to sense the dust on the solar panel. If dust is present, then the surface is less exposed to light and hence the LDR resistance increases.

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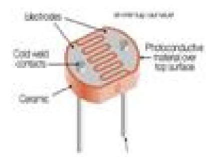
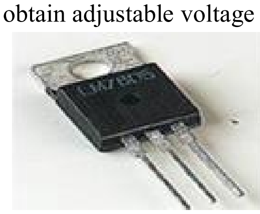
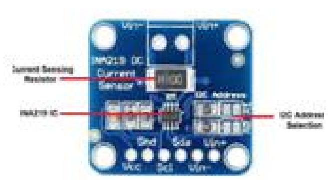


DTH11 Sensor : This DFRobot DHT11 Temperature & Humidity Sensor features a temperature & humidity sensor complex with a calibrated digital signal output. By using the exclusive digital-signal acquisition technique and temperature & humidity sensing technology, it ensures high reliability and excellent long-term stability.

LM 7805 voltage regulators : The LX78MXX series of three terminal regulators is available with several fixed output voltages making them useful in a wide range of applications. The voltage available allows these regulators to be used in logic system, instrumentation, Hi – Fi and other solid state electronic equipment. Although designed primarily devices can be used with external component to obtain adjustable voltage and current.



INA219 Sensor : The INA219 is a current shunt and power monitor with an I2C- or SMBUS-compatible interface. The device monitors both shunt voltage drop and bus supply voltage, with programmable conversion times and filtering. A programmable calibration value, combined with an internal multiplier, enables direct readouts of current in amperes. An additional multiplying register calculates power in watts.



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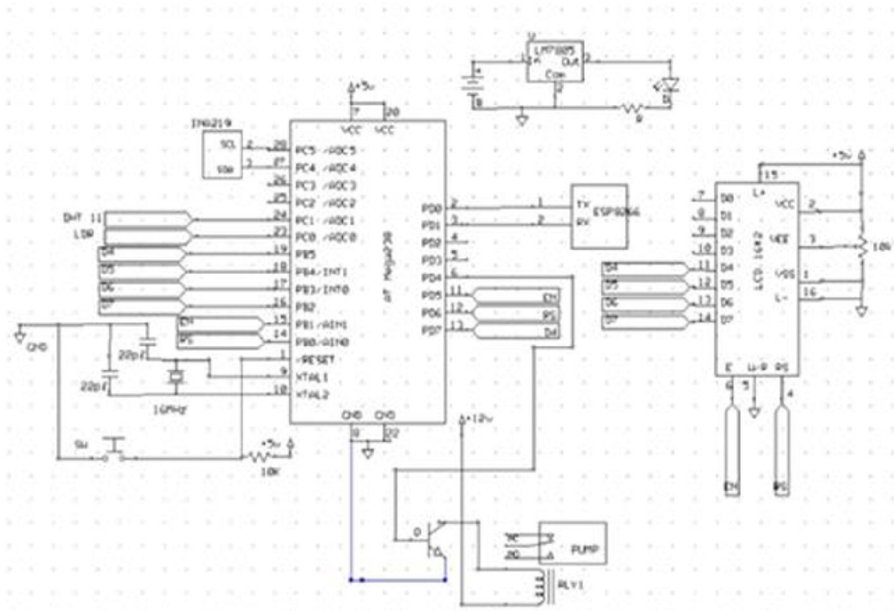
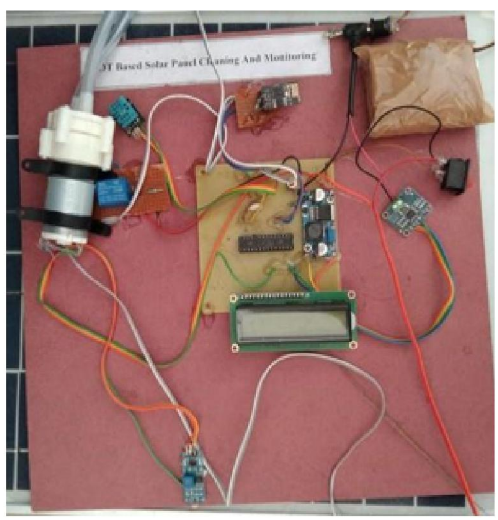
V. CIRCUIT DIAGRAM



VI. EXPERIMENTAL SETUP



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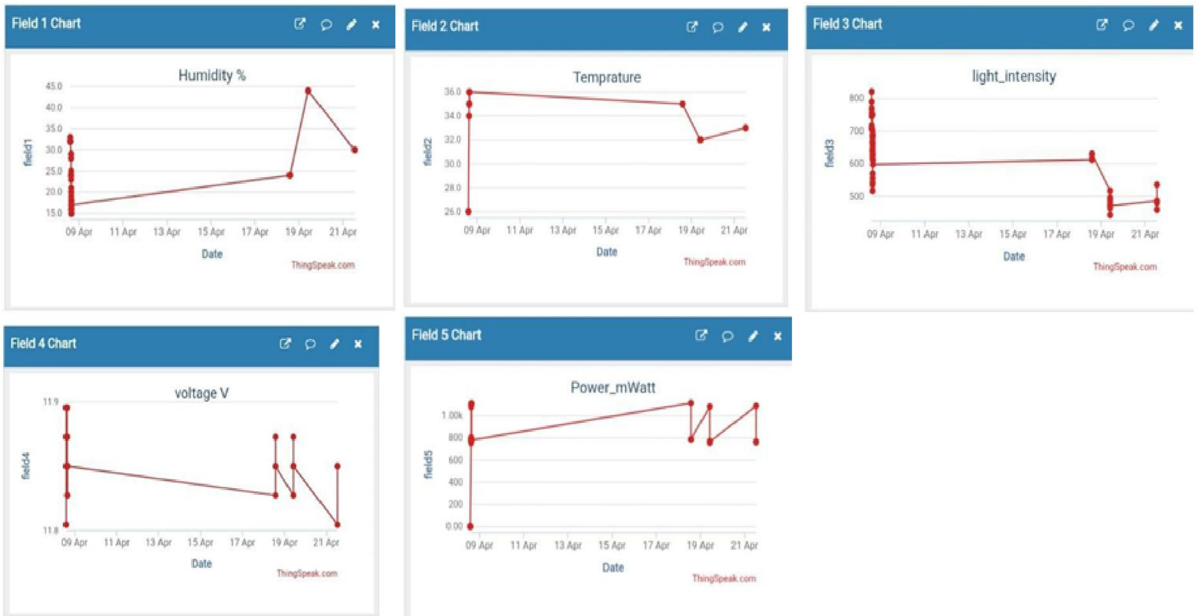
VII. RESULT



VIII. CONCLUSION

The proposed IoT-based solar panel cleaning and monitoring system offers a practical and efficient solution to one of the most persistent challenges in solar energy generation performance degradation due to dust and environmental factors. By integrating automated cleaning mechanisms with real-time monitoring through IoT sensors and wireless communication, the system ensures optimal panel efficiency, reduces manual maintenance, and supports remote diagnostics. The project demonstrates the feasibility of combining low-cost hardware components like microcontrollers and sensors with cloud platforms to develop a smart, scalable, and sustainable solution. As solar energy becomes more integral to global power systems, such intelligent systems will play a crucial role in maximizing energy output, reducing operational costs, and promoting the adoption of clean technologies. This work lays a strong foundation for future enhancements involving AI, robotics, and large-scale deployment across diverse environmental conditions.

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