Solar Panel Cleaning Robot

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Abstract **-** Solar energy is one of the most abundant and eco-friendly sources of renewable energy available on Earth. Solar photovoltaic (PV) panels are widely used to harness this energy without causing environmental pollution. However, the efficiency of panels significantly depends on the amount of sunlight they receive. The accumulation of dust and other particles on the surface of the panels can drastically reduce their efficiency. To maintain optimal performance, regular cleaning of PV panels is essential. This paper proposes the design and development of an autonomous solar panel cleaning robot that periodically cleans PV panels without human intervention. The cleaning mechanism involves blowing air, spraying liquid, and wiping the surface with a wiper to remove dust and debris. Any remaining moisture is naturally dried through exposure to sunlight. The robot is IoT-enabled, allowing remote control and monitoring, which reduces manual labor in large-scale solar plants. By automating the cleaning process, the proposed system enhances the overall efficiency of solar power generation.

Keywords- Solar Panel, Cleaning, IOT, Dust Detection, Robot

INTRODUCTION

In recent years, solar energy has emerged as one of the most promising and sustainable alternatives to conventional energy sources. Photovoltaic (PV) panels are widely deployed in both urban and rural areas to harness solar energy. However, one of the major challenges affecting their performance is the accumulation of dust, dirt, and other environmental pollutants on the surface of the panels. Studies have shown that even a small layer of dust can reduce the efficiency of solar panels by up to 30%. Traditional cleaning methods often require manual labor, access to water, and regular maintenance cycles, which are not only labor-intensive but also economically and environmentally unsustainable, especially in remote or large-scale solar farms.

To overcome these challenges, our project focuses on the design and development of a Solar Panel Cleaning Robot that operates autonomously and requires minimal human intervention. The system is built using an ESP32 microcontroller, which acts as the brain of the robot, coordinating all movement and communication. It incorporates an ESP32-CAM module that streams real-time video footage over a local network, allowing users to visually monitor the cleaning process by accessing a specific IP address through any web browser. This eliminates the need for external cloud servers or complex networking infrastructure.

The movement of the robot is enabled by DC motors connected via an L298N motor driver module, which receives control signals from the ESP32. Power is supplied by a rechargeable lithium-ion battery, ensuring portable and uninterrupted operation. Z44N MOSFETs are used to switch the motors on and off efficiently, while a TTL converter ensures seamless serial communication between the ESP32 and ESP32-CAM. For user interaction, the robot uses a Bluetooth module (HC-05) that receives directional commands from a mobile application or remote controller. This dual-communication setup—Bluetooth for control and Wi-Fi for monitoring—makes the system both robust and user-friendly.

The proposed system offers a scalable and cost-effective solution for solar panel maintenance. It not only minimizes the need for manual labor but also enhances panel longevity and energy output. The combination of IoT-based monitoring, wireless control, and automated operation represents a significant step forward in smart energy infrastructure.

Methods And Materials

This project utilizes a combination of hardware components to create a remote-controlled solar panel cleaning system equipped with real-time visual feedback. The core of the system is the **ESP32** microcontroller, which functions as the main controller to manage inputs and outputs across the cleaning mechanism. For wireless communication, an **HC-05 Bluetooth module** is used, enabling the ESP32 to receive control commands from a mobile device via a Bluetooth controller application. Visual monitoring is made possible with the **ESP32-CAM**, a camera-enabled microcontroller that streams live video to the user, allowing for real-time observation of the cleaning operation.

Power for the entire setup is provided by a **lithium-ion battery**, which supplies the necessary voltage and current to the controller, motors, and other peripherals. The **L298 motor driver** is employed to control the movement of the cleaning mechanism's wheels and brushes. It receives PWM signals from the ESP32 and drives the motors accordingly. The movement system is built on a **4-wheel chassis**, providing mobility and support for the brush and pump mechanisms.

For switching high-power components like the water pump, an **IRFZ44N MOSFET** is integrated into the system. The MOSFET acts as an electronic switch controlled by the ESP32 to activate the pump without directly exposing the controller to high current. A **TTL to USB module** is used to program the ESP32-CAM module, as it requires a serial communication interface for uploading code and debugging.

The system is powered by a **battery pack**, which ensures portability and continuous operation during cleaning. All components are assembled on the chassis in a compact and efficient layout to facilitate both wired connections and mechanical movement.

The method of operation begins with initializing the ESP32 and establishing a Bluetooth connection through the HC-05 module. The user pairs their smartphone with the Bluetooth module and sends control commands via the Bluetooth controller app.

These commands are interpreted by the ESP32, which then activates the motor driver to control the chassis wheels and cleaning brushes. Simultaneously, if the cleaning process requires water, the ESP32 sends a signal to the IRFZ44N MOSFET, which switches the water pump on or off depending on user input. The ESP32-CAM streams live video, allowing the user to monitor the cleaning in real time and make adjustments as needed. After cleaning is complete, the system can be safely powered down, and the battery recharged for future use.

This method allows for an efficient, low-cost, and remotely operated solar panel cleaning mechanism, especially suitable for residential or small-scale solar installations.

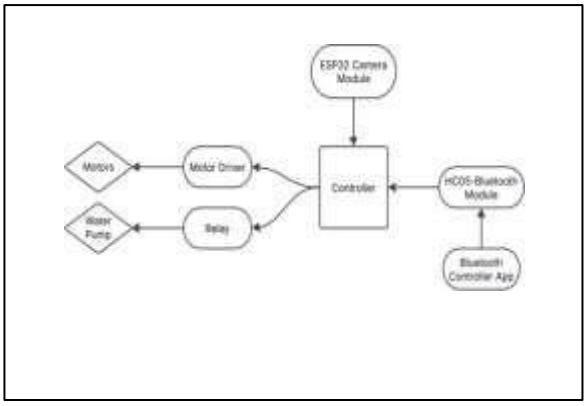

Fig1:- Block Diagram of System.

TABLE:-1

HARDWARE REQUIREMENT FOR THE DEVELOPMENT OF THE PROJECT

Hardware specification	Quantity
Stepper Motor	5
12V Lithium-ion battery	6
ESP32 camera module	1
L298N Motor Driver	2
HC-05 Bluetooth Module	1
TTL(Transistor-Transistor Logic)	1
Z44N MOSFET	1
ESP32 MOD	1

TABLE:-2

SOFTWARE REQUIREMENT FOR THE DEVELOPMENT OF THE PROJECT

Software Specification	**Software Name**
Utilized Source Code	Arduino IDE
Designing & Simulation	Proteus
Robot Control	RC Bluetooth Controller

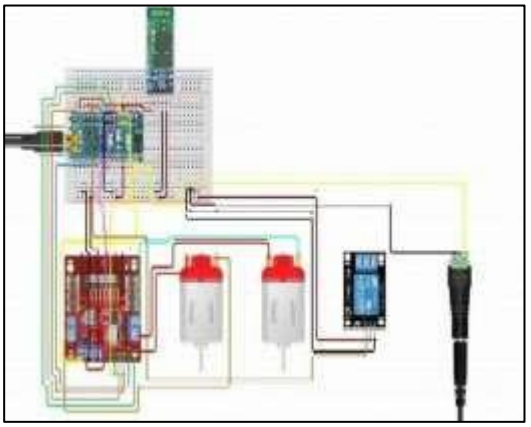

Fig2:- Circuit Diagram of System

The This circuit represents the complete hardware setup of a solar panel cleaning robot, where the ESP32 microcontroller is the central control unit. At the top of the breadboard, the HC-05 Bluetooth module is connected to the ESP32 via TX and RX lines, enabling

wireless communication between the robot and the user's smartphone using a Bluetooth controller app.

On the left side of the circuit, an L298N motor driver module is connected to the ESP32. This module controls the two DC motors (depicted in red), which drive the wheels of the 4-wheel chassis. These motors are powered directly through the motor driver using an external power source, ensuring they receive sufficient current for operation.

To the right of the motor driver, a relay module is used to control the water pump. The ESP32 sends a control signal to the relay through one of its digital output pins. When activated, the relay completes the circuit, allowing current to flow from the power supply to the pump, thus starting the water spray.

A voltage regulator or external power adapter (shown on the far right) supplies power to the motor driver, ESP32, relay module, and pump. Proper grounding and voltage supply lines are routed throughout the breadboard to maintain stable operation across all components.

Overall, this circuit layout effectively brings the conceptual block diagram to life by integrating the motor control, water pump actuation, wireless communication, and central processing through a cohesive, compact, and efficient design.

This circuit simulation represents a solar panel cleaning mechanism controlled by an Arduino Nano. At the core of the system is the Arduino Nano, which interfaces with an L293D motor driver IC responsible for driving four DC motors. These motors would typically be connected to brushes or wipers that move across the surface of solar panels, removing dust and debris to maintain efficiency.

The system includes indicator LEDs to signal different operational states, such as when the cleaning process is active or when a specific action is being performed. Communication with the system is handled via a serial interface, simulated here with a virtual terminal. Through this terminal, control commands like 'F' for forward, 'B' for backward, and other directional or operational instructions can be sent to the Arduino.

These commands dictate how the motors should operate,effectively controlling the cleaning mechanism's movement.

Fig3:- RC Bluetooth Controller.

A simulated Bluetooth serial module is also present, showing how the system could be wirelessly controlled using a smartphone or external device. Overall, this simulation demonstrates a practical, remotely controllable, automated system designed to keep solar panels clean, ensuring their optimal performance with minimal manual intervention.

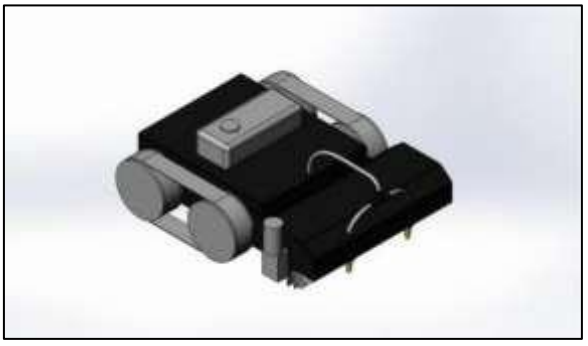

Fig4:- 3D Prototype of System.

RESULT AND DISCUSSION

Fig5:- Verified Simulation Coding

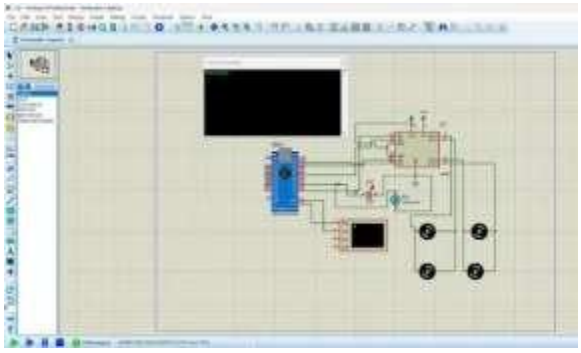

Fig6:- Proteus Simulation.

CONCLUSION

The efficiency of solar energy production is significantly reduced due to the accumulation of dust and debris on solar panel surfaces. The proposed Solar Panel Cleaning Robot is designed to address this issue by providing anautomated solution that effectively removes dust using a combination of air-blowing, liquid spraying, and mechanical brushing. The robot's movement is remotely controlled and monitored via an RC Bluetooth Controller app, offering ease of operation and flexibility. Additionally, the integration of the ESP32-CAM module enables real-time live camera monitoring, allowing users to oversee the cleaning process remotely through a web-based interface. Powered by rechargeable lithium-ion batteries, the robot operates independently without reliance on external power sources. Experimental observations have shown a notable increase in power generation when using this system compared to traditional manual cleaning methods. By automating the cleaning process and enabling remote visual supervision, the proposed system not only reduces manual labor but also enhances the overall efficiency and productivity of solar power generation.

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