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IoT based Solar Panel Cleaning Rover

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Abstract

The primary objective of this proposed study is to design a system for effectively maintaining the cleanliness of solar panels, thereby enhancing their performance and longevity through an Internet of Things-based solar panel cleaning rover equipped with a sensors, and manual automation capabilities. A suite of sensors, including dust sensors, enables the rover to gather relevant data about the cleanliness status and ambient conditions surrounding the solar panels. Manual automation features empower users to intervene and control the rover's movements and cleaning actions as needed, providing flexibility and customization in operation. Furthermore, the rover is designed to connect directly with water tanks, facilitating an autonomous water supply for the cleaning process. A sponge brush mechanism is integrated into the rover's design to effectively remove dust from the solar panel surfaces. The proposed work has developed a prototype of the IoT-based solar panel cleaning rover, which has been tested to demonstrate its effectiveness in improving solar panel efficiency and reducing maintenance efforts.

Keywords: IoT, Solar Panel Cleaning, Rover, Sensors, Manual Automation.

1. Introduction

To ensure that the solar panels work efficiently, it is essential to keep them clean and well-maintained. Dust particles on the solar panel can greatly reduce energy output, so regular

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cleaning is necessary. The IoT-based solar panel cleaning rover automates the cleaning process, ensuring consistent and maximum energy production. The rover integrates sensors, a brush, a water tank, DC motors, an Arduino Uno microcontroller, a motor driver, a pump motor, and wheels. The rover's forward and backward movements can be controlled through a Bluetooth-connected mobile application. The Proportional-Integral-Derivative (PID) control algorithm ensures precise and stable operation by adjusting motor speeds for accurate trajectory and effective cleaning. The system's remote monitoring and control capabilities provide real-time feedback, enhancing both convenience and reliability. This automation significantly reduces labor and costs involved in manual cleaning, ensuring that the solar panels operate at peak efficiency and maximizing energy production. The proposed system maximizes the efficiency of the solar energy system by addressing maintenance challenges.

1.1 Objectives

To develop an IoT-based solar panel cleaning rover that optimizes energy production through timely, automated cleaning and real-time monitoring, enhancing efficiency while reducing downtime, manual labor, and operational costs.

2. Literature Review

Advancements in technology for managing solar panels improve their reliability and reduce costs by addressing dirt accumulation that decreases energy output. The existing research highlights the benefits of smart systems for real-time monitoring and cleaning of solar panels, though it emphasizes the need for more empirical research to better understand their effectiveness [1].

Ghafoor et al. [2] proposes an automated cleaning system for solar panels using IoT technology and the Messaging Queuing Telemetry Transport protocol to improve efficiency. The system, controlled by an ESP-32 microcontroller and monitored through the Adafruit dashboard, enhances solar panel performance by 30% through real-time data and automated cleaning.

Najmi et al. [3] presents the brief review on the solar panel cleaning aspects and discusses the how the dust accumulation affects the energy production and efficiency. Megantoro et al [4] presents the design of a mobile robot, replacing the human labor to clean PV.

Kumar et al [5] presents a solar panel cleaning robot that automatically cleans panels by blowing air, spraying liquid, wiping dust, and drying with a brush. Remotely controlled through IoT, the robot reduces manual labor and is self-powered by a solar panel it carries, enhancing power generation efficiency through regular cleaning.

Rao et al [6] describes the implementation of a smart solar panel cleaning system that uses Internet of Things (IoT) technology for dust monitoring, advanced analysis, and system control, which boosts the overall efficiency of the solar PV panels.

Hashim et al. [7] explores the innovative robotics technology for cleaning photovoltaic panels. The proposed system monitors power generation and cleans the panel surfaces as needed, with control managed through a mobile app.

Singarapu et al. [8] proposed a timed system that uses water and wipers to clean solar panels, utilizing advanced technology to enhance performance, reliability, consistency, cost-effectiveness, and scalability

Tranca et al. [9] presents an architecture for a custom-built, low-power autonomous Industrial IoT controller designed specifically for PV solar panel cleaning solutions. This controller connects to the internet for remote monitoring and supports VPN, iptables, and other advanced security features that are typically not available in current devices.

Chakaborty et al. [10] introduces a modern solution: a remote-control robot operated through smartphones. This Arduino-based autonomous robot connects to mobile phones through Bluetooth technology, offering a compact design that saves time and labor. It is highly efficient for large-scale solar panel systems. Jadhav et al. [11] develops an IoT-based dust cleaning system to maintain PV panel efficiency. Khadka et al. [12] The authors suggest a decision-making model that uses key parameters, data processing techniques, and machine learning tools to address soiling issues in solar PV panel cleaning systems and improve performance in PV power plants.

Supriya et al. [13] suggests a solar panel cleaning system that uses a rechargeable battery and a mobile app to control horizontal movement and gear motors through the internet. It employs a Linear Piezoelectric Actuator (LPA) and an SVM-based energy management system to keep solar panels clean and efficient, even in challenging conditions, using water and soft sponges to avoid damage. The proposed work also has developed a solar panel cleaning robot including the sensors, a brush, a water tank, DC motors, an Arduino Uno microcontroller, a motor driver, a pump motor, and wheels. It uses the MIT App Inventor to develop a mobile application to control the movements of the rover remotely and see the status of the solar panels.

3. Proposed Work

The proposed solar cleaning rover system uses an Arduino Uno (ATmega328P) as the main controller to manage all the components. It integrates various sensors and motors to perform its functions. The ultrasonic sensor (HC-SR04) is used for detecting obstacles and the edges of the solar panels, aiding in the rover's navigation. The dust sensor (GP2Y1010AU0F) measures the cleanliness of the solar panels, providing essential data on the need for cleaning. The rover's movement is powered by DC motors, controlled through a motor driver (L298N), while the pump motor is used to spray water for cleaning purposes. Communication between the rover and the mobile app is facilitated by a Bluetooth Module (HC-05), enabling wireless control and real-time monitoring of the system’s operations. The Figure 1 below depicts the block diagram of the proposed.

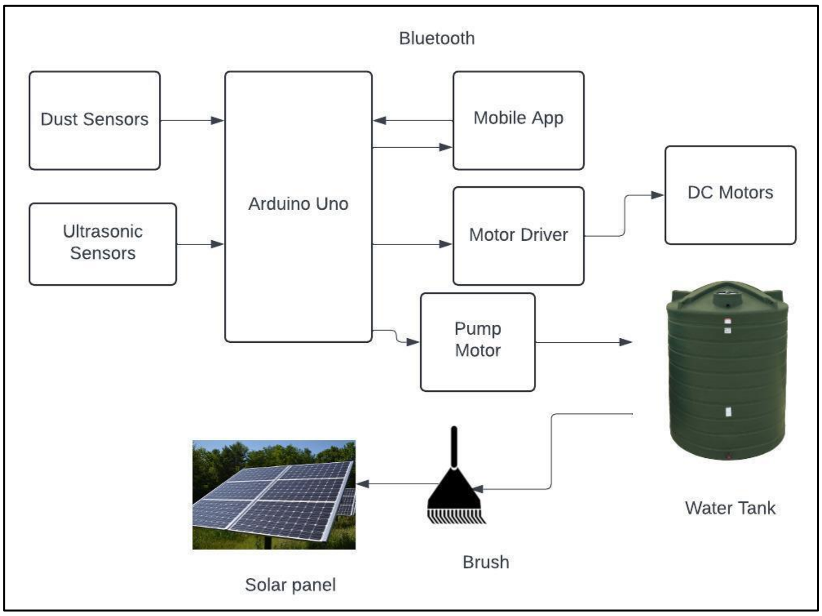

Figure 1. Block Diagram of the Proposed

3.1 Working Principle

The proposed system is designed integrating components like sensors (ultrasonic and dust sensors), DC motors, motor drives, pump motors, wheels with Arduino Uno for effective solar panel cleaning. The Mobile App developed using the MIT App Inventor is used to control the robot's movement and display the cleanliness status of the solar panels, connecting to the Arduino Uno through Bluetooth. The Arduino Uno acts as the central controller, receiving commands from the Mobile App and processing data from the sensors. These sensors monitor the cleanliness of the panels and other environmental conditions, sending data directly to the Arduino Uno. The Arduino Uno then sends commands to the motor driver, which controls the DC motors that drive the robot's wheels, enabling its movement. The Proportional-Integral-Derivative (PID) control algorithm facilitates precise and stable navigation, allowing the rover to effectively move across the surface of solar panels. Additionally, the Arduino Uno directs the pump motor to regulate the flow of water from the water tank, which supplies water for cleaning. The water is delivered to the brushes, which clean the surface of the solar panels. This coordinated setup ensures that the solar panels are cleaned efficiently, with the Mobile App providing real-time control and status updates. The Table 1 below shows the details of the hardware components used.

Table 1. Hardware Components Used

S.No	Integrated Circuit	Components	Purpose
1.	Micro Controller	Arduino UNO (ATMEGA328P)	The central unit controlling all the sensors and motors.
2.	Sensors	Ultrasonic Sensor (HC-SR04)	For obstacle and edge detection.
		Dust Sensor (GP2Y1010AU0F)	To measure the cleanliness of the solar panels.
3.	Motors	DC Motors (Generic with L298n Motor Driver)	To drive the rover.
		Pump Motor (Generic)	To spray water for cleaning the panels.
4.	Communication	Bluetooth Module (HC-05)	For wireless communication with the mobile app.

The code for the solar panel cleaning robot is developed using C++ in the Arduino IDE and uploaded to the Arduino Uno to control and coordinate the robot's various functionalities. This includes modules for sensor integration, motor control, decision-making, and potentially user interface development. These modules work together to enable autonomous navigation, obstacle detection and avoidance, precise cleaning operations, and efficient resource utilization. The Table 2 below illustrates the details of the software used in the proposed work.

Table 2. Software's Used

S.No	Components	Purpose
1.	Arduino UNO Environment Development	An open-source microcontroller board used for building and programming the rover's control system.
2.	Operating System (Windows 10)	The platform used to run development tools and software necessary for programming and controlling the rover.
3.	BLender	A 3D modeling and simulation software used for designing and visualizing components of the rover.

Figure 2 below illustrates the rover's movement. The mobile app communicates with the Arduino through Bluetooth. Upon receiving commands from the app, the Arduino sends control signals to the motor driver. The motor driver then controls the DC motors based on these signals from the Arduino, which drives the wheels of the rover

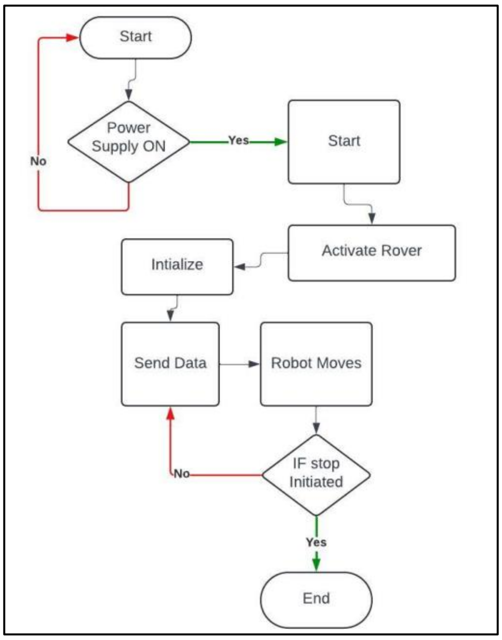

Figure 2. Flow Chart

3.2 Schematic Layout

Figure 3 shows the circuit diagram of the solar panel cleaning rover

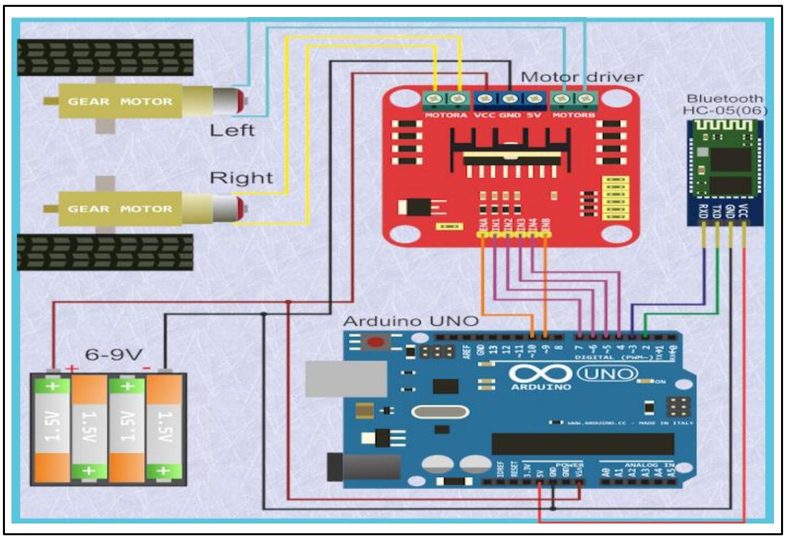

Figure 3. Circuit Diagram

Power Supply

- The positive terminal of the battery (red wire) connects to the Arduino's "VIN" pin which supplies power to the board.
- The negative terminal of the battery (black wire) connects to the Arduino's "GND" pin which is the ground connection.

Motor Driver

- The "VCC" pin on the motor driver connects to the Arduino's "5V" pin which provides power to the motor driver.
- The "GND" pin on the motor driver connects to the Arduino's "GND" pin for ground connection.

Control Signals

- Two control pins (labeled "MOTOR A" and "MOTOR B" on the motor driver) connects to Arduino's digital pins 6 and 9.
- These pins are used to control the direction and speed of the two gear motors.

Bluetooth Module

- The Bluetooth module (HC-05 or HC-06) has four connections:
- VCC connects to the Arduino's "5V" pin to supply power.
- GND connects to the Arduino's "GND" pin for ground connection.
- TX (transmit) connects to the Arduino's digital pin 0 (RX) to receive data from the Bluetooth module.
- RX (receive) connects to the Arduino's digital pin 1 (TX) to transmit data to the Bluetooth module.

Gear Motors

- Two gear motors connect to the motor driver board.
- The specific connections will vary depending on the motor driver used in the circuit

4. Results and Discussions

The IoT-based solar panel cleaning rover maximizes the efficiency of the solar panels by keeping them clean. The Figure 4 and Figure 5 shows the top view and the side view of the proposed solar panel cleaning rover.

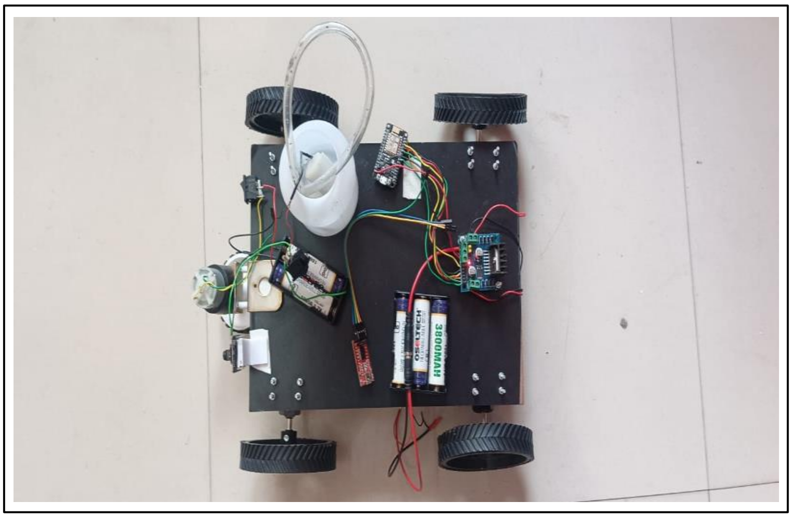

Figure 4. Hardware Prototype (Top View)

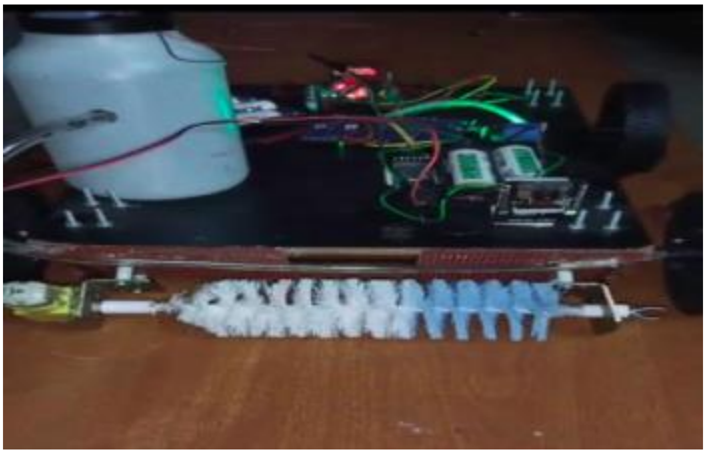

Figure 5. Hardware Prototype (Front View)

An IoT-based solar panel cleaning rover maximizes the solar panel efficiency by automating the cleaning process. It uses sensors and internet connectivity to monitor panel conditions and starts cleaning when dirt is detected. The rover employs soft brushes and to clean the panels gently, avoiding damage. With real-time data transmission, users can remotely monitor and control the rover. Powered by solar energy and equipped with obstacle detection, the rover operates autonomously, reducing the maintenance costs and manual labor while increasing energy output and extending the life of solar installations.

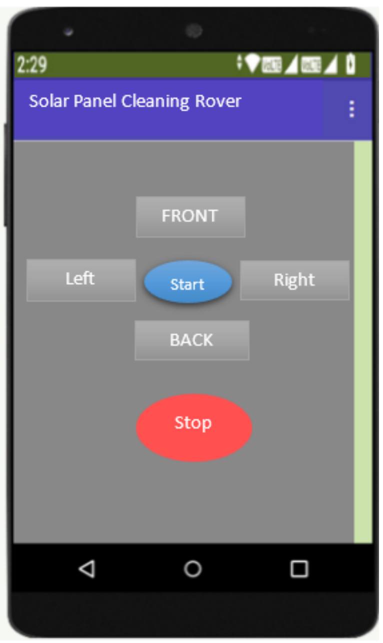

Figure 6. Mobile Application

The mobile application for the IoT-based solar panel cleaning rover features a user-friendly interface. The users can manually control the rover's movements with forward, backward, left, right, and stop buttons (Figure6). Additional options such as starting and stopping water dispensing, monitoring sensor data for obstacles and edges, and setting cleaning schedules can be included in future. The application can also be designed to provide access to system settings for maintenance and configuration, ensuring an efficient and intuitive user experience.

4.1 Benefits

The solar panel cleaning robot offers several benefits. It maximizes energy production by keeping panels consistently clean, leading to higher efficiency and increased revenue for solar power plant operators. Cost savings are achieved through reduced labor costs and minimized water and cleaning solution usage. The robot enhances safety by eliminating the need for human operators to climb onto roofs or navigate hazardous terrain. Regular cleaning extends the lifespan of solar panels, preventing efficiency degradation over time. Additionally, the robot promotes environmental sustainability by conserving water and reducing the carbon footprint associated with solar panel maintenance.

5. Conclusion

The IoT-based solar panel cleaning rover represents a significant advancement in the maintenance and efficiency of solar energy systems. By integrating an array of components including an Arduino Uno microcontroller, DC motors, a motor-driven brush, a water tank, a pump motor, Bluetooth connectivity, and various sensors. The proposed rover automates the cleaning process, ensuring solar panels operate at their maximum potential by maintaining cleanliness and efficiency. The deployment of a Proportional-Integral-Derivative (PID) control algorithm facilitates precise and stable navigation, allowing the rover to effectively move across the surface of solar panels. The ability to remotely control the rover through a user-friendly mobile application enhances its practicality and ease of use. Key findings from the research demonstrate the rover's ability to significantly improve the cleanliness and efficiency of solar panels. By mitigating the accumulation of dust, the system optimizes energy output, contributing to the overall sustainability and economic viability of solar power installations. The energy-efficient design, powered by a lithium battery, ensures prolonged operation, making the rover a practical solution for various solar panel installations. The successful implementation of this research emphasizes its potential to reduce maintenance costs and labour associated with manual cleaning. This innovation is particularly beneficial for large-scale solar installations, where manual cleaning is often impractical and costly.

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