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Solar Panel Dirt Detection and Cleaning System

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Abstract:

The proposed solar panel dirt detection and cleaning system improves the efficiency in generating output voltage that integrates Arduino micro-controller with voltage recognition technology to enhance the efficiency of solar energy harvesting. The system utilizes voltage divider circuit to identify dirt or debris on the solar panel surface by analyzing changes in output voltage produced by the solar panel. Along with voltage divider circuit, LDR (Light Dependent Resistor) sensor is utilized to enable the cleaning process only in day time when the intensity level of the LDR is more than threshold value. Upon detection, the Arduino micro-controller triggers a cleaning mechanism to remove the identified dirt. The cleaning mechanism can be designed using actuators, brushes and other appropriate tools. The Arduino's programmability allows for customization of cleaning intervals, ensuring timely maintenance. The output voltage measurement plays a crucial role in spotting dirt accumulation on the solar panel. This ensures accurate detection, minimizing false positives and optimizing the cleaning process. Additionally, the system can be enhanced with data logging capabilities, enabling users to monitor the cleanliness status of the solar panels over time. This information can be valuable for predictive maintenance and overall system performance analysis. The voltage analysis for detecting dirt with integration of Arduino offers an intelligent and automated solution for solar panel maintenance, ensuring consistent energy output by keeping the panels free from surface contaminants.

Keywords—Arduino micro-controller, Dirt accumulation, Solar panel, Voltage divider circuit, LDR sensor.

INTRODUCTION

Solar energy stands out as an exceptional alternative for power generation due to its renewable nature and its clean, waste-free operation. Solar energy harnesses electricity by employing solar panels to convert sunlight into electrical power. The accumulation of dirt on solar panels obstructs their capacity to effectively absorb sunlight, leading to a significant decline in electricity generation. As solar energy adoption increases in diverse applications, the demand for maintenance escalates. However, addressing dirt buildup presents recurrent and unpredictable challenges, complicating efforts to manage its deposition rate. Regular cleaning is essential to mitigate the impact of dirt on solar panels. Factors such as location, climate, and surrounding environment influence the frequency and intensity of maintenance required. Desert regions, for instance, may experience more dust accumulation, necessitating more frequent cleaning compared to areas with lower dust levels.

In urban environments, pollutants like soot and particulate matter can further exacerbate dirt buildup, requiring specialized cleaning techniques. Additionally, seasonal variations and weather events such as rainstorms or sandstorms can affect the rate at which dirt accumulates, making maintenance scheduling more complex. Efforts to address this challenge include the development of automated cleaning systems and advanced coating technologies to minimize dirt adhesion.

I.   LITERATURE SURVEY

The proposed method [1], is unsupervised and fully automated. This method relies on the perception and analysis of variations in color sensitivity within a given environment. By assessing changes in color, this technique can swiftly and automatically identify alterations. It operates by analyzing the intensity of light reflected in the red, green, and blue scale with corresponding wavelength output. In study [2], The proposed approach involves analyzing the surfaces of photovoltaic (PV) modules using image processing techniques. The acquisition of images is performed by aerial robotics such as equipped with high resolution cameras. This process utilizes the MATLAB Image Processing Toolbox for analysis. The article

[5] states about Photovoltaic Soiling Index (PVSI) that serves as a metric to gauge the performance of photovoltaic (PV) panels when subjected to dust accumulation, both in controlled Standard Test Conditions (STC) and in real-world operating environments across different geographical locations. It helps assess how efficiently PV panels generate electricity despite varying levels of soiling caused by dust, aiding in optimizing their performance and maintenance strategies worldwide. According to [6], the annual power loss triggered by dust deposition habitually ranges from 5% to 30%. It examines transparent electrodynamic screen (EDS) for removing dust, as frequently as needed, from the solar collectors without water. Power output efficiency is maintained greater than 90% compared to that of the panel under clean conditions. The paper [8], near the entrance of a solar panel, there's a powerful force

called thermophoresis, that pushes tiny particles away. Using computer simulations based on how air flows around the panel and how its temperature changes, the paths of these tiny particles where tracked. If the particles smaller than a micrometer, this thermophoretic force creates an area where they don't stick to the solar panel surface. Essentially, it keeps the panel cleaner. This effect is particularly noticeable when the panel is a bit warmer than the surrounding air during daylight hours. [12], This paper delves into various studies concerning how dust particles and solar PV modules interact, focusing on how dust accumulates on the glass surfaces due to electrostatic forces. Additionally, it explores how the airflow, particle movements, and electrostatic fields influence the laws governing particle deposition. [14] This report explores, four key forces involved in the initial stages of dust accumulation: capillary, van der Waals, electrostatic, and gravitational forces. It's discovered that in high humidity, capillary force plays a major role, while in dry conditions, van der Waals force is predominant. By analyzing real-world data from solar panels, a new mathematical model is proposed to predict when dust accumulation rates shift from low to high based on relative humidity levels. Additionally, the impact of surface roughness is studied by comparing adhesion forces on clean glass surfaces to those coated with special anti-dust titania film.

II.   DESIGN AND CONSTRUCTION OF DIRT DETECTION AND CLEANING SYSTEM

TABLE I.   LIST OF COMPONENTS

No	Component
1	Arduino Uno
2	Voltage Divider Circuit (30k, 4.7k Resistors)
3	LDR (Light Dependent Resistor)
4	Submersible Motor
5	Servo Motor
6	LCD (Liquid Crystal Display)
7	I2C Bus
8	Relay
9	Battery (9V)
10	Solar Panel(12V)

The system comprises both hardware and software components. Hardware encompasses the physical elements, with the microcontroller serving as the central component. Software components, on the other hand, include the operating systems that coordinate the system's functions, ensuring consistent cleanliness of the solar panels. These components are detailed in Table 1.

The system is composed of an LDR sensor, Voltage Divider Circuit that comprises 4.7k and 30k resistors, LCD along with I2C bus for efficient communication between the microcontroller and the LCD module with minimal wiring.
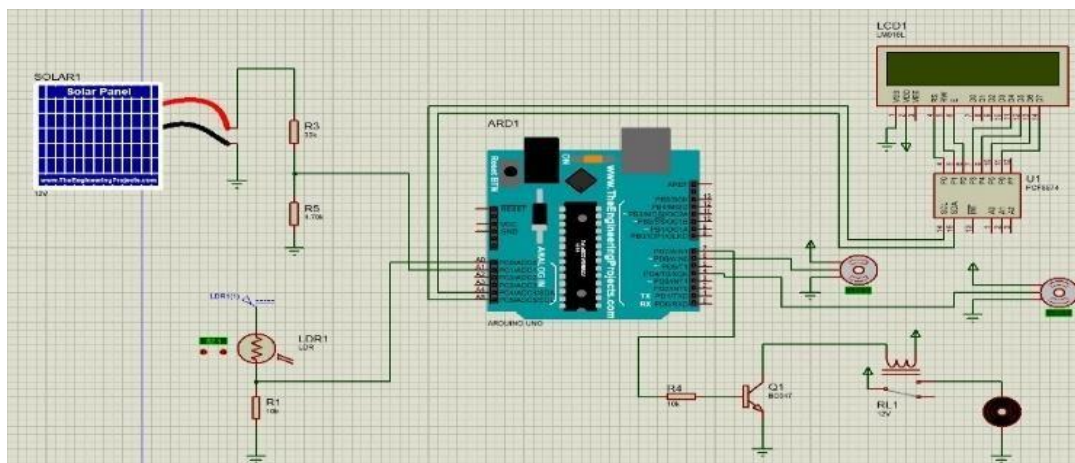

Fig. 1. Simulation of the components using Proteus software

An LDR, or Light Dependent Resistor, is a type of resistor whose resistance changes with the intensity of light incident upon it. LDRs are typically composed of a semiconductor material such as cadmium sulfide (CdS) or cadmium selenide (CdSe) sandwiched between two electrodes. When light falls on the semiconductor material, photons are absorbed by its atoms, generating electron-hole pairs. This process increases the conductivity of the material, reducing its resistance.

A voltage divider is a simple series resistor circuit. It's output voltage is a fixed fraction of its input voltage. The divide-down ratio is determined by two resistors. It's a method of adjusting an input voltage to a lower level by distributing it across the two resistors in the divider. The ratio between the two resistors determines how much of the input voltage each resistor gets, essentially dividing the voltage. The output voltage can be calculated using,

$$Vout = Vin(R1/R1+R2)$$
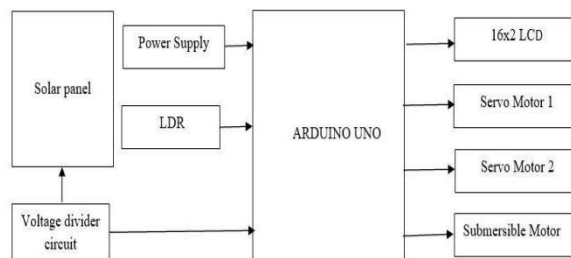
III. IMPLEMENTAION

A. Proposed System

Fig. 2. Block diagram of proposed system

A voltage divider circuit is a tool used to measure the output voltage of a solar panel. By comparing the measured voltage with a predetermined threshold, we can determine if the drop in voltage exceeds an acceptable level, indicating the presence of dust or dirt. This method allows us to detect when cleaning or maintenance is necessary to ensure optimal solar panel performance.
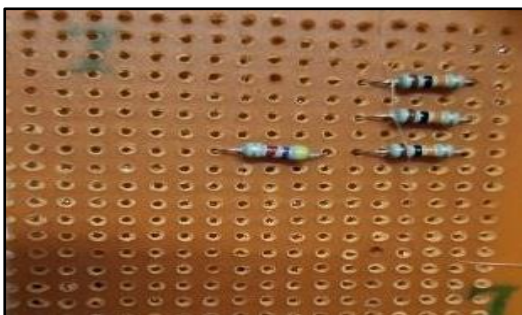

Fig. 3. Voltage Divider Circuit

Fig. 4. LDR Sensor

In addition to the voltage divider circuit, a Light Dependent Resistor (LDR) sensor is employed to ensure that cleaning activities are conducted only during daylight hours. The LDR sensor detects changes in light intensity. By incorporating it into the system, we can ensure that the cleaning process is triggered only when there is sufficient daylight available to generate power from the solar panel. This prevents unnecessary energy consumption and ensures that cleaning activities are carried out effectively when the solar panel is actively producing electricity. The wiper mechanism, assisted by a servo motor, executes the cleaning process. The servo motor provides precise control over the movement of the wiper, ensuring smooth and effective cleaning across the surface. By integrating a servo motor, the wiper mechanism can adjust its speed, angle, and position as needed, enhancing its ability to remove dirt, debris, or other contaminants from the surface with accuracy and reliability. Additional refinement is done to enhance the cleaning process by using submersible motor. Cleaning the surface with water would provide optimized cleaning process. This combination of the wiper mechanism and submersible motor offers a versatile solution for maintaining cleanliness in various applications, from automotive to industrial settings.

B. Flowchart

The system starts by gauging the ambient light intensity using the LDR sensor. If the detected light intensity surpasses a predefined threshold, signaling ample illumination, it moves on to examine the voltage level via the voltage divider circuit. When the voltage fall below a specified threshold, indicating a potential power deficiency, the system triggers a series of steps for cleaning the surface using wiper mechanism
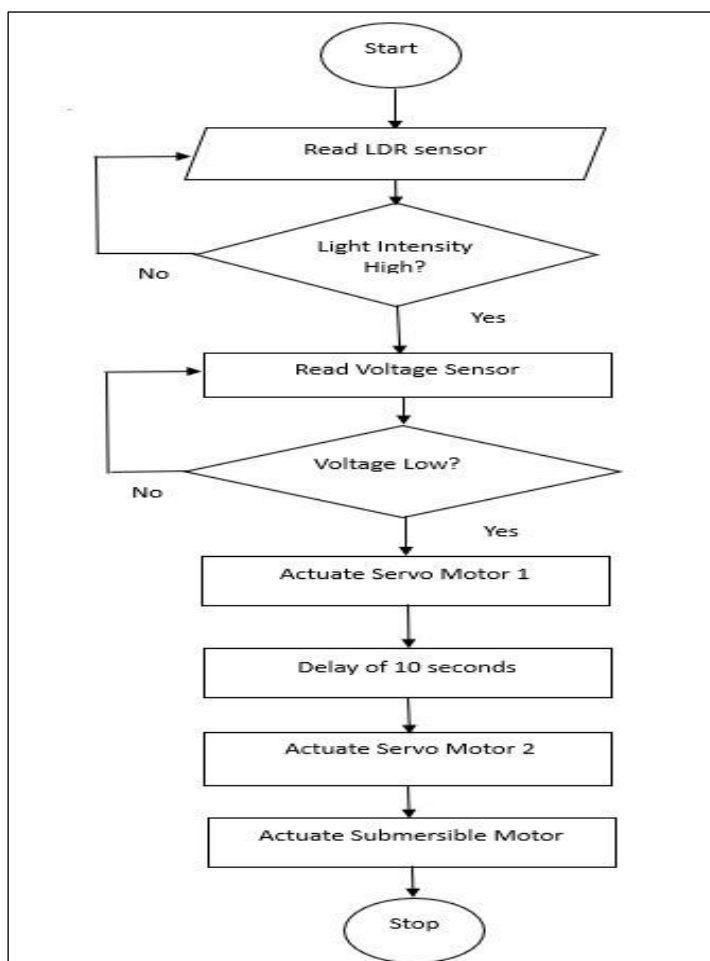

Fig. 5. Flowchart of the dirt detection and cleaning process

Initially, it engages servo motor 1, controlling the movement of one wiper, and introduces a 10-second delay. The delay is implemented to prevent any potential collision between the wipers. Subsequently, it activates servo motor 2, managing another wiper's motion, ensuring comprehensive coverage of the solar panel surface for cleaning. Along with wiper mechanism, the submersible motor will be activated. Finally, once the cleaning task is completed, the system halts all operations.

However, if the light intensity is not high or if the voltage is not low, signifying satisfactory conditions, the system terminates without engaging any of the motors, preserving energy and preventing unnecessary actions.

The subsequent code that effectively meets the criteria for initiating the cleaning process is:

```
if(ldrsensor >80)
  {
  if(in_voltage <8.0)
    {
    lcd.clear();
    lcd.print("Solar Cleaning");
    lcd.setCursor(0,1);
    lcd.print("in Progress");
    digitalWrite(relay,LOW);
    for (pos = 90; pos >= 10; pos -= 1)
      {myservo.write(pos);
      delay(10);
    }
    delay(1000);
    for (pos = 10; pos <= 90; pos += 1)
      {myservo.write(pos);
      delay(10);
    }
    delay(1000);
    for (pos = 90; pos >= 0; pos -= 1)
      {myservo_1.write(pos);
      delay(10);
    }
    delay(1000);
    for (pos = 0; pos <= 90; pos += 1)
      {myservo_1.write(pos);
      delay (10);
    }
    delay(1000);
    }
  else {
    myservo.write(90);
    myservo_1.write(80);
    digitalWrite(relay,HIGH);
    }
  }
}
```

IV. RESULTS

This method aims to correct the dirt detection methods previously in use. Hence, a high-speed rolling brush equipped with a water system arrangement is designed to improve the cleaning of the solar panel. Obtained results confirm the possibility of the proposed, real-time with a low-

cost sensing device that consists of a chip sensor of LDR that is positioned on the solar panel. By applying the developed method, an automated solar panel cleaning system can quickly sort
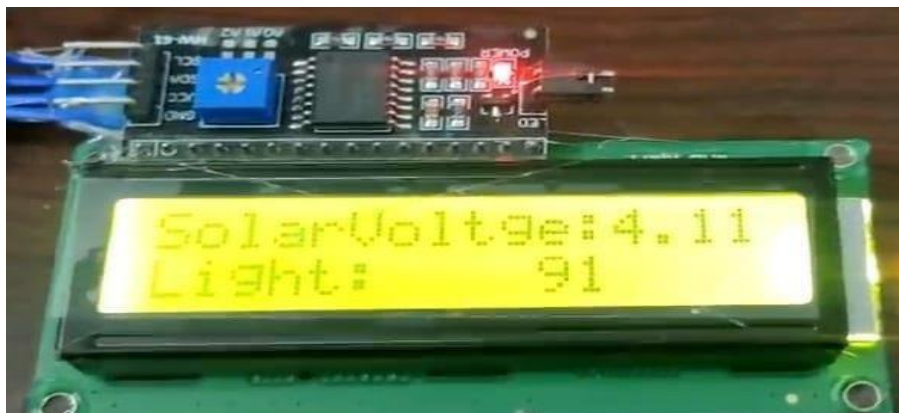
the dirt condition according to the voltage generated by the panel.

Fig. 8. Display of output votage readings and light intensity percentage

V. CONCLUSION

An inexpensive and output voltage measurement of the solar panel that can distinguish the clean and dirty panel surfaces according to their voltage change has been proposed. It demonstrates the advancement of a solar panel dirt detection and cleaning system that signifies a notable progression in renewable energy technology. It represents an enhancement in the efficiency, sustainability, and reliability of solar energy generation.

By integrating sensors to detect both light intensity and voltage levels, the system ensures timely cleaning action only when necessary by enabling prompt action to uphold peak performance and conserving energy and resources. The utilization of servo motors enables precise control over the movement of wipers, facilitating thorough cleaning without the risk of collision. Moreover, the automated cleaning process reduces the need for manual intervention, minimizing maintenance costs and labor requirements.

Overall, this system not only enhances the efficiency and longevity of solar panels but also contributes to sustainable energy production by maximizing their output potential.

By linking the solar panel dirt detection and cleaning system to biological sciences, you can develop innovative, efficient, and sustainable solutions. Biomimicry, microbial cleaning, enzyme-based cleaners, and bioinspired sensors are just a few examples of how biological principles can enhance the performance and environmental compatibility of these systems. This interdisciplinary approach not only improves solar panel efficiency but also promotes sustainability and ecological harmony.

Linking solar panel dirt detection and cleaning system to biological sciences involves exploring how biological principles, processes, and organisms can inspire or enhance the technology. Here are some ways to make this connection:

Biomimicry in Cleaning Mechanisms

Inspiration from Nature:

Lotus Effect: The lotus leaf has a superhydrophobic surface that repels water and dirt. By mimicking this property, you can develop self-cleaning coatings for solar panels that reduce dirt accumulation.

Gecko Feet: Gecko feet have microscopic structures that allow them to cling to surfaces. Robotic cleaners can use similar principles to adhere to and move across vertical or inclined solar panels efficiently.

 2. Microbial Detection and Cleaning

Microbial Communities:

Biofilm Detection: Biofilms can form on solar panels, especially in humid environments. Techniques from microbiology can help detect and analyze these biofilms.

Biodegradation: Certain microbes can degrade organic matter on the panel surfaces. Harnessing these microbes in a controlled manner can aid in cleaning.

3. Photosynthesis Efficiency

Analogies with Photosynthesis:

Light Absorption: Studying how plants optimize light absorption can lead to better designs for solar panels and coatings that minimize dirt impact.

Chlorophyll Degradation: Understanding how plants manage the degradation and regeneration of chlorophyll can inspire maintenance cycles for solar panels.

4. Enzyme-Based Cleaning Solutions

Enzymatic Reactions:

Enzyme Cleaners: Enzymes used in biological processes can break down organic contaminants on solar panels. Enzyme-based cleaning solutions can be an eco-friendly alternative to chemical cleaners.

5. Sensor Technology from Biology

Biological Sensors:

Bioinspired Sensors: Sensors mimicking the sensitivity of biological systems, such as insect antennae or plant roots, can be developed to detect minute particles of dirt or dust.

-Biosensors: Integrating biosensors that react to organic contamination can provide real-time data on panel cleanliness.

6. Symbiotic Systems

Symbiotic Relationships:

Plant-Fungi Symbiosis: Just as plants and fungi form mutualistic relationships (e.g., mycorrhizae) for nutrient exchange, a symbiotic relationship could be formed between the solar panels and microorganisms that help keep them clean.

7. Ecological Impact and Sustainability

Sustainable Practices:

Ecological Footprint: Assessing the ecological impact of cleaning methods, ensuring they do not harm local ecosystems or biodiversity.

Water Conservation: Using minimal water through efficient, biologically-inspired cleaning techniques, preserving water resources.

8. Environmental Monitoring

Ecological Monitoring:

Bioindicators: Using bioindicators to monitor the environmental conditions around solar farms, ensuring that the cleaning processes do not negatively affect local wildlife.

Pollinator Health: Ensuring that cleaning processes and chemicals used do not harm pollinators, which are crucial for ecosystem health.

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