Journal of Computers, Mechanical and Management

Journal homepage: www.jcmm.co.in

Volume 1 Issue 2

CLEAROSO: A Cleaning Robot for the Solar Panels

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Abstract

Non-renewable power sources being sustainable have a major impact on controlling global warming. Solar energy is one of the prominent non-renewable energy sources that has been increasingly utilized in recent years to generate solar power using solar panels. The accumulation of dust (also known as soiling) on the surface of solar panels reduces the quantity of sunlight reaching the solar cells beneath, lowering the efficiency of the solar panel. To fully utilize their specified capacity, they must be cleaned regularly, often with water. Cleaning solar panels, especially when large in numbers, consumes much time. The cleaning of solar panels has become complex, complicated, and ultimately costly due to the growing water shortage problem in most parts of the world. The current study also suggests the development of a solar panel cleaning robot to address the issues connected with the traditional technique of solar panel cleaning. In the present work, an appropriate methodology was developed to balance the robot on the solar panel, having the ability to clean the panels with no wastage of water and no damage to the panels. Since the proposed cleaning process is automated, cleaning time was significantly reduced, and the usage of water and the effort of the personnel was eliminated. Several cleaning trials were conducted using the robot, and the result indicated an increase in the overall efficiency of the solar panel cleaning process.

Keywords: Photovoltaic Panel Cleaning; Sensors; Robotics; Water-Free Cleaning; Real-Time Systems

1 Introduction

Solving today's environmental issues necessitates long-term prospective initiatives for sustainable development, and renewable energy (RE) resources appear to be among the most efficient and effective alternatives in this respect [1]. Global and regional trends imply that renewable energy sources will soon meet most global energy demands [2]. In other words, RE is predicted to alleviate energy crises by playing a critical role in satisfying future power demands [3]. Solar and wind energy are the most promising and effective renewable energy sources, encouraging interest in expanding their use globally [4, 5]. Global solar energy output is predicted to grow faster than any other energy source until the middle of the century, particularly in locations with high levels of dust and/or anthropogenic particle pollution, such as major portions of India, China, and the Arabian Peninsula [6]. India's RE potential is around 900 GW from diverse sources, with solar power contributing 83% and hence is the major contributor [7]. Photovoltaic (PV) energy production through PV panels is one of the most promising and mature renewable energy production technologies [8]. PV panels are composed of several cells linked together to create power at the correct voltage. Photovoltaic panels are essentially direct current (DC) devices. They are used in conjunction with an inverter to generate alternating current (AC) [9]. Photovoltaic cells or solar cells are diodes that convert sunlight directly into electricity and have a wide surface area exposed to the sun.

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Received: 14 September 2022; **Accepted:** 17 December 2022; **Published:** 31 December 2022

DOI: 10.57159/gadl.jcmm.1.2.23013.

The performance of a PV cell is affected by irradiance (the radiant flux received by a surface per unit area), light spectrum, and cell temperature. The maximum current rises in proportion to the rising irradiance, improving cell performance. For a known value of voltage (V) and current (I), the efficiency of cells with an area (A) at irradiance (G) is expressed by Eq. [1]. The irradiance considered for the calculation of the efficiency of a PV solar cell is considered as 1000 W/m2, as per the standard test condition (STC) [10]. There exist varieties of solar PV cells, but the crystalline silicon (c-Si) solar cell accounts for 80% of the global market [11–13].

$$\eta = \frac{VI}{AG} \tag{1}$$

Solar panels absorb solar energy and effectively generate electrical output. However, environmental conditions impact and influence electrical output energy [14]. Dust deposition is one of the environmental elements that have a major impact on the efficiency of solar modules [15–17]. Dust (visible, unseen, floating and falling solid particles) is estimated to reduce electricity output by around 1 and 11 GW in India and China, respectively. Here, "dust" refers to minute, crushed particles less than 500 µm in size that enter the atmosphere from various sources, including industrial facilities, construction sites, and dust storms [18]. When sunlight strikes the surface of the PV modules, it activates them; consequently, when dust particles accumulate on the panel, the area that transmits photons reduces, preventing light energy from reaching the PV cells. This problem may be prevented by planning and implementing an efficient cleaning system [19], [20]. Manual cleaning, vacuum suction cleaning, automatic wiper-based cleaning, and electrostatic precipitator-based cleaning are some of the most often used PV panel cleaning methods. The first two are the most traditional and frequently used cleaning methods requiring active human intervention [21]. Various scholars have sought to tackle dust buildup issues and enhance the efficiency of solar panels while reducing human intervention through various designs and methods, particularly by designing automated robots.

For example, Krauter [22] developed a robotic device that used a silicone rubber foam brush to clean PV modules more efficiently. Demain et al. [23] devised an autonomous self-cleaning mechanism based on components such as light-dependent resistor (LDR) sensors, sprayers, and wiper units controlled by solar panels' output. Sera and Baghzouz [24] devised an alternate method by cleaning the panel surface using a brush embedded in disk equipment with a polymer tip. Swain et al. [25] created a self-powered solar panel cleaning mechanism that uses a brush operated by direct current (DC) motors and an Arduino microprocessor to clean the SPV panel. Chailoet and Pengwang [26] created a solar panel cleaning robot using a spiral brush and a rubber sweeper. Ghodki [27] created an infrared-based dust mitigation device controlled by a robotic arm. Ronnaronglit and Maneerat [28] created a solar panel cleaning robot that uses a gear motor and an Arduino microprocessor. Kumar et al. [29] created a self-powered robot remotely controlled by the Internet of Things (IoT) to clean the panel surface and reduce the need for human intervention.

Using the previous study as inspiration, the current work aims to integrate multiple technologies, including a DC motor, an infrared system, a Bluetooth system, and an Arduino microprocessor, to create a solar panel cleaning robot (CLEAROSO). Furthermore, the difficulty in regulating CLEAROSO's movement was addressed using specifically constructed frame-calibrated motions. After cleaning a given region, the developed robot proceeds autonomously to the next uncleaned portion of the panel, eliminating the need for human intervention throughout the cleaning process.

2 Materials and Methods

2.1 System overview

As seen in Fig. 1 (a), the CLEAROSO block diagram comprises an input, processor, and output components. The robot's primary element is the input mechanism, comprising one traditional manually controlled switch unit and two infrared (IR) sensors. The action of the rollers and sliders was controlled by infrared sensors that were positioned in such a manner that they recognized the position of each panel using position objects (or stoppers) attached to the bottom. Panel positioning was accomplished by the use of stoppers that reflect IR radiation. The input data and information were passed to the second element, a processor (type Arduino - ATmega328P microcontroller) integrated using the Arduino IDE. The last element is the output source, comprising a DC motor for controlling robot movement and a Bluetooth module integrated with Android apps for testing voltage and current levels. Figure 1 (b) depicts the hardware connections. A mechanical frame that moved right and left and reached all display regions was employed to increase performance. The robot was intended to move in linear motion during the cleaning procedure. A short-term cleaning mechanism was used to complete the operation as quickly as possible. Due to Bluetooth limitations, the optimal functioning range for CLEAROSO was determined to be 20 meters. Each hardware component's desired functionality was achieved using Bluetooth modules and gear motors. The Bluetooth module was connected to Arduino Uno and successfully accepted signals from the android application. Later, the processed signal was sent to the microcontroller. The gear motor received the signals from the Bluetooth module through the microcontroller. The user input sent through the Bluetooth module moved the motor forward and backward. The various components used in making CLEAROSO are given in Table 1. The infrared sensor, once activated, began to measure the robot's movement distance. For the robot's movement distance of less than 4 cm, it was programmed to continue to move forward, and for a distance exceeding 4 cm, the robot was programmed to move backward. Once the time delay set in the microcontroller reached 1000 ms, the robot was programmed to stop moving in the backward direction and resume moving in a straight line. The described movement tends to repeat until the robot is shut down.

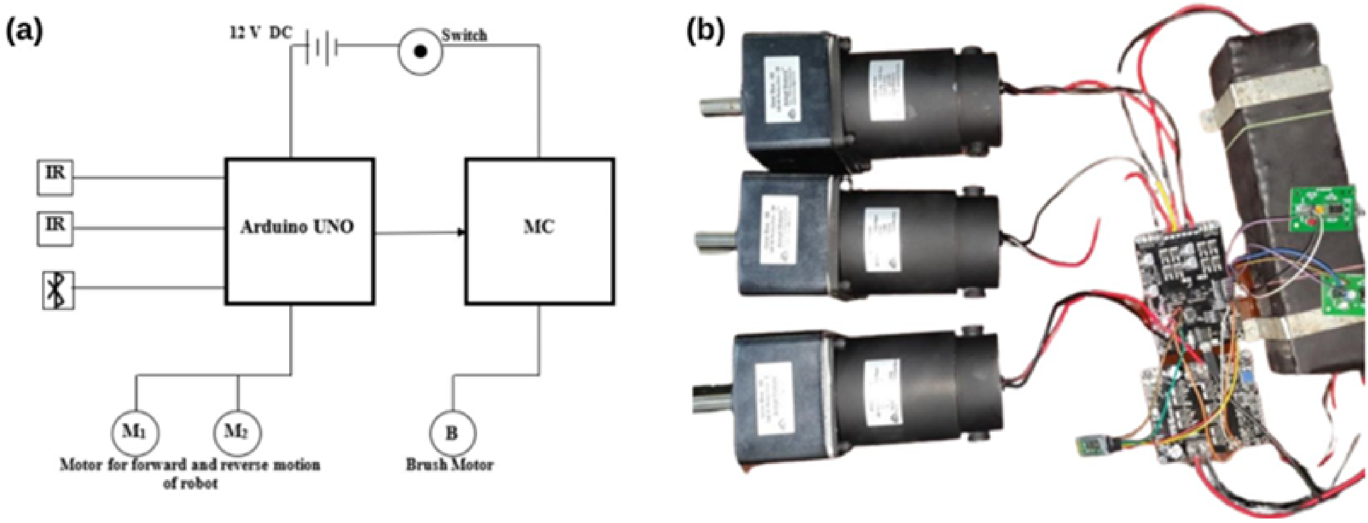

Figure 1: CLEAROSO System: **(a)** Block diagram;**(b)** motor connections to the main circuit.

Component	**Type**	**Technical specifications**
Arduino Uno	Microcontroller	ATmega328P Weight of 25 grams Length of 68.6 mm Width of 53.4 mm
Infrared (IR) sensor	Sensor	Magnetic sensor
Stepper Motor	DC Motor	24 V Gear Motor Torque: 173 kg-cm Rotational speed: 15 RPM Power output: 30 W
Bluetooth Module	Serial Communication Device	TX / RX Pin
Arduino Software (IDE)	Software	Arduino programming language (based on wiring)
Solar panel	Prototype (miniature version)	Length = 100 cm Width = 60 cm

Table 1: Hardware and software list

3 Solar panel characteristics

Several experiments were conducted to clean a dirty solar panel to assess the efficiency of the developed solar panel cleaning robot (CLEAROSO). In these experiments, fine sawdust was utilized to simulate solar panel dust. For the experimental procedure, the current and voltage of undusted, dusty and cleaned solar panels were measured every hour, starting from 12.00 pm until 3.00 pm. Since the area of the PV solar cell prototype was already known, the power was determined by measuring the voltage and current for the solar panel prototype in its dusty condition and after dust removal. Afterward, the efficiency, η was calculated using Eq. [1].

4 Results and Discussion

The developed robot was coded to move in a straight line, forward and backward, because it was tested on a small solar panel. Suppose the developed robot is planned to be tested on a larger array of solar panels. In that case, the robot's movement can be coded as per proper walking path to efficiently clean all the solar panels. Table 2 summarizes the measured data, calculated power and solar panel efficiency obtained using Eq. [1]. From the results obtained after the dust-removal process, the power and solar panel efficiency have increased by an average value of 53.65%. The increase in efficiency proves the developed robot's effectiveness and workability. Moreover, compared to traditional solar cell cleaners, CLEAROSO proved to be a better option as the cleaning time got halved, and the usage of water and human intervention was eliminated. The efficiency can further be increased by modifying the cleaning mechanism and improving the kinematics of the proposed model, and thus can be considered a possible extension to the presented work. The investigation of speed and work efficiency at an angular-positioned solar panel can also be considered a future scope of the presented work.

Table 2: Hardware and software list.

Time	Dusty panel		Clean panel		Power (W)		Efficiency (%)
	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Dusty Panel	Clean panel	
12.00 pm	20.27	0.076	20.27	0.146	1.54	2.96	49.32
01.00 pm	20.22	0.097	20.22	0.152	1.96	3.07	51.22
02.00 pm	22.31	0.094	22.31	0.151	2.10	3.37	56.15
03.00 pm	23.28	0.083	23.28	0.149	1.93	3.47	57.81

5 Conclusion

This paper describes the development of a fully assembled solar panel cleaning robot. The Arduino platform is used to develop the control algorithm and cleaning sequence. The robot is powered entirely by rechargeable batteries, and the movements are obtained using motors. The efficiency of the robot working was quantified using the power output by the solar panel prototype. After cleaning, the solar panel generated more than 50% of its power. The increased power output demonstrates the developed CLEAROSO robot's efficient workability.

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Funding Declaration

This research did not receive any grants from governmental, private, or nonprofit funding bodies.

Author Contribution

Nikheel N. Deshmukh: Conceptualization, Visualization, Investigation Methodology, Data curation, Writing- Reviewing; **Devendra Chitale**: Supervision, Writing- Reviewing; **Raghavendra C. Kamath**: Supervision, Writing- Original draft preparation, Writing- Reviewing.

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