Development of Mobile Robot System for Monitoring and Cleaning of Solar Panels

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ARTICLE INFO

Article history:
Received: 15 February 2020
Revised: 11 May 2021
Accepted: 19 August 2021

Keywords:
Mobile robot
Solar panel cleaning
Dust and dirt accumulation

ABSTRACT

This work addresses the mobile robot system for monitoring and cleaning of solar panels. In the proposed work, a cleaning system using mobile robot has been developed. One of the problems observed with the solar panel efficiency is the dust accumulation which impacts on the solar panel output. This is because it obstructs the solar radiation to incident on the panel surface. Therefore, cleaning of solar panels on regular basis using the robot system is necessary and has been presented in this work in order to overcome this problem. The developed robot can work automatically at a preset time, and can be manually controlled by users in order to undertake the monitoring and cleaning tasks. A series of tests have been conducted and the experimental results demonstrate that the proposed robot system can work effectively. Additionally, the solar panels utilizing the proposed system provides higher energy output compared to the dust accumulated solar panels. This results in an increase in efficiency of overall solar modules and a decrease in workforces for cleaning of the solar panels.

1. INTRODUCTION

Energy demands are increasing rapidly. Thus, the need to conserve energy and utilise available energy efficiently is very important. There are many forms of renewable energy which occur naturally such as solar, hydro, wind, geothermal, and biomass. Solar energy is considered to be one of the most abundant sources of renewable energy [1, 2]. The investments of such energy are increased continuously in many developed countries [3], as well as in the Greater Mekong Subregion [4]. A photovoltaic cell (PV) or solar cell is a component that changes the sunlight into the electric energy. The amount of sunlight that can be changed into electric power is known as the solar cell efficiency. There are several factors that need to be taken into account in order to guarantee the optimal performance of the solar panels, such as temperature, solar shading, and bird droppings. Dust accumulation is also one of the factors that adversely impact on the solar panel output as it obstructs solar radiation to incident on the module surface. As a result, it reduces the overall performance of the solar system. It can generally assume a reduction of approximately 10% - 40% if the panels are not clean properly for a period [5, 6].

To overcome this problem, cleaning of solar panels on regular basis is necessary. However, labour-based cleaning method for solar modules is expensive and uses a large amount of water. Moreover, it is risky because the workforce needs to climb a slightly high building. Therefore, the cleaning robot system has been presented in this work in order to eliminate the dust and dirt in the solar modules without water usage. The developed system can work automatically and manually. It can also be used as a way to detect breakage or damage of solar panels while cleaning. The system can be operated remotely as the users can control and access all information of the system via web-application. A detail of developed cleaning robot system is provided as follows: Section 2 describes the literature review and the background of the relevant works regarding researches in cleaning robot system. The development of the proposed system is detailed in Section 3, while section 4 addresses the experimental implementation and evaluation of the developed robot system. The conclusion of this work is lastly presented in Section 5.

2. BACKGROUND AND STATEMENT OF THE PROBLEM

To cope with the problem of dirt and dust on solar panels, several cleaning methods have been proposed, which include human cleaning, semi-automated and fully automated cleaning systems [7] - [9]. Shahzada P. Aly et al. [10], propose the robot system which aims to enhance the efficiency of current dry-cleaning systems. The system is designed to work at a preset timing. It is accessible,

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manageable, and can complete its tasks automatically. As a result, it is able to replace the usage of workforces for cleaning of the solar panels. Jawale et al [11] indicate that dust and dirt on solar panels significantly decrease the efficiency of the solar modules. So, they propose a robot system to enhance the performance of solar panels. The robot cleaning system is simple; however, it can increase the electric power output of the solar panels up to 130% after the cleaning process. M. A. Jaradat et al. [6] address the financial lost due to the decrease of the electric power output of the dirty solar panels with the accumulation of dust particles. They report that the electric power output losses approximately 10% - 40% per year. Therefore, they introduce an autonomous cleaning system using a mobile robot moving on a rail platform that allows the mobile robot to navigate from one panel to the other panels. The system has been designed based on the mechanism that permits flexible adaptation for different dimensions of the solar panels.

Besides the experimental robot systems, commercial robot systems for cleaning process are also available, including the E4 robot, SMR-640AD model, Solarbrush robot, and Washpanel robot. The E4 robot has been developed by Ecopia Company [12]. It requires water free while cleaning the dust and dirt on the solar panels using the brushes made from the microfibers. The robot utilizes its on-board solar panel for charging its battery. It consumes a slight electric energy from the battery during the cleaning process.

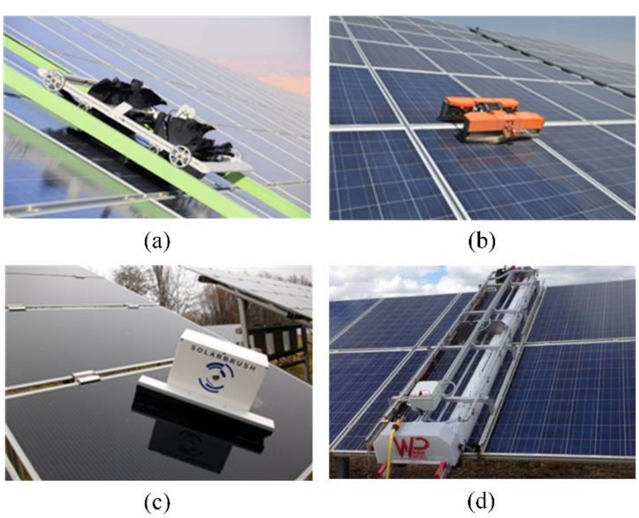


Fig. 1. (a) E4 robot [12], (b) SMR-640AD model [13], (c) Solarbrush [14], and (d) Washpanel robot [15]

Mirailkikai company presents the SMR-640AD model which is a lightweight, battery-powered robot that can autonomously remove dust and dirt on the solar panels [13]. The robot starts cleaning by moving through the panels. It can change direction and move to the next modules when it reaches the edge of the solar panels. Users need only to monitor the robot while it works. The robot then stops its cleaning process when it arrives at the goal location. For the Solarbrush robot, it has been developed by Solarbush company [14]. The robot is lightweight, autonomous for dry cleaning solar panels. It can cross the gaps and moves on the panels which are tilted up to 35 degrees to the ground. The cleaning brushes can be installed on the robot in order to brush the dust, sand, and dirt away.

Additionally, an Italian company called Washpanel [15] produces the robot that cleans the solar panels by moving its cleaning brush while navigating around the panels. It can be deployed automatically using a 12V battery. Figure 1 (a) – (d) displays the E4 robot, SMR-640AD model, Solarbrush robot, and Washpanel robot, respectively.

3. DESIGN OF PROPOSED MOBILE ROBOT SYSTEM

In this section, control architecture for the mobile robot system [16] particularly designed for fully automated cleaning processes of rooftop solar panels has been presented. A microcontroller (Arduino Mega) provides a control of the robot system which completes the cleaning process automatically while a small single-board computer (Raspberry Pi) provides the internet connection for the users to remotely control the system via the developed web-application. It also offers a live stream (via webcam) during the robot operation in order for the users to detect dirt and breakage of panels. Figure 2 displays the overview of the proposed robot architecture while Figure 3 illustrates the concept design of the robot system and the web-application.

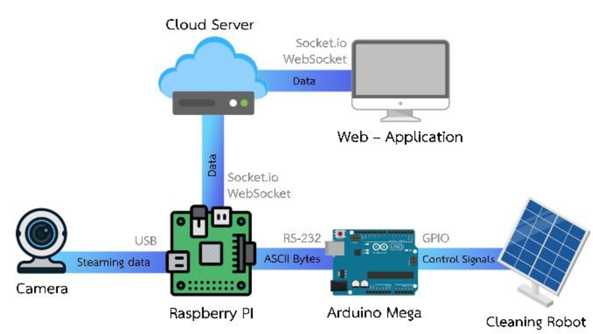


Fig. 2. Hardware architecture of the proposed robot system.

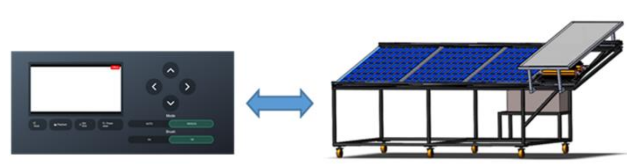


Fig. 3. Concept design of web-application and the robot system.

The proposed robot can clean the solar panels without water usage (dry-cleaning) as it utilises the microfibers (bristles) to remove dust and dirt on the panels. The physical dimensions of the robot are 0.55m x 0.60m, while its locomotion employs the rail mechanism, mounted on the solar panels, to move along the panel area during the cleaning process. Therefore, aluminum profiles are utilised as robot frame and rail platform while the pulley system, specially designed for the proposed robot structure, is applied to provide a smooth transition between the panels. The robot makes use of the dry-cleaning brushes to eliminate the dust on the solar panels, thus no water is required in the process. Additionally, the proposed robot system is able to charge the battery using the energy from the solar panels, thus it will be ready for the next cleaning process all the time.

In the standby state, the robot is parked in the docking station and stores electrical energy while waits for starting its task. At a preset time (autonomous mode), the robot begins to move from its docking station to the first part of the panel area (see Figure 4). It then starts rotating the cleaning brushes while moving down vertically through the solar panel (Y-axis). When the cleaning process is completed, the brushes stop rotating and vertically move up. The robot then moves horizontally to the 2nd part of the panel area (X-axis) and the cleaning brushes start rotating again. This cycle continues repeatedly until the end of the solar panels (the 6th part). The robot then returns to its docking station and begins to charge while waiting for the next instructions (manual mode). If there are no further instructions for the mission, the robot will automatically start working again in the next day at the preset time.

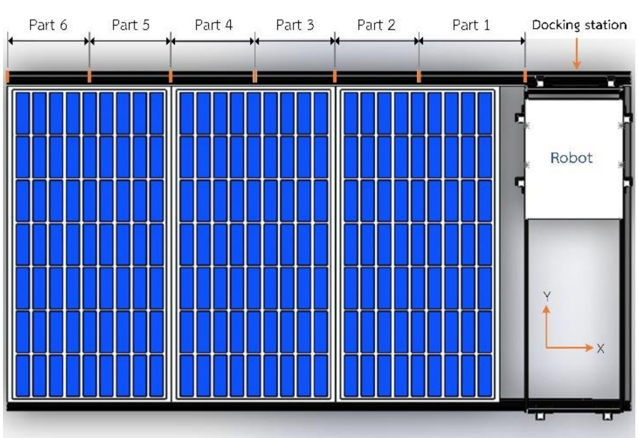
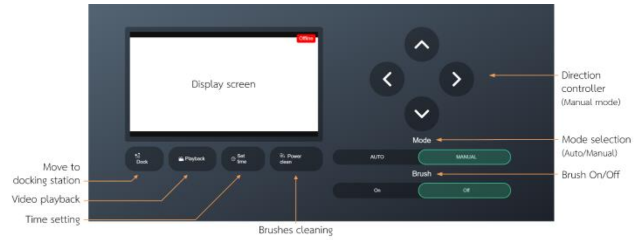
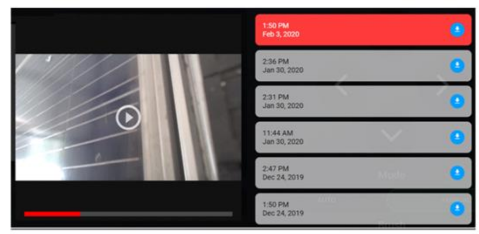


Fig. 4. Robot operation scheme.

Additionally, the users can watch the live stream video during its operation through the web-application or watch later with the recorded video files. Figure 5 displays the descriptions of the developed web-application while Figure 6 demonstrates some examples of robot operation in which Figure 6 (a) displays the robot moving out of its docking station and starts cleaning the 1st part. Figure 6 (b) – (e) show the robot navigating to the 3th – 6th parts of the panel area and runs its cleaning process while Figure 6 (f) illustrates the robot finishing its cleaning task and navigates back to its docking station.



(a) Web-application screen

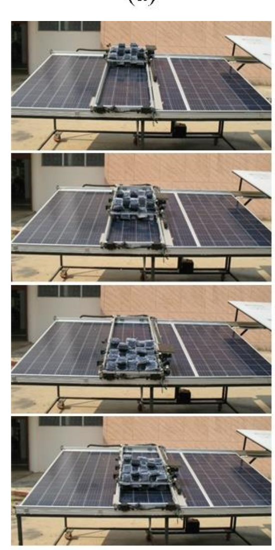


(b) Video playback screen

Fig. 5. Details of web-application.

(a)

(b)



(c)

(d)

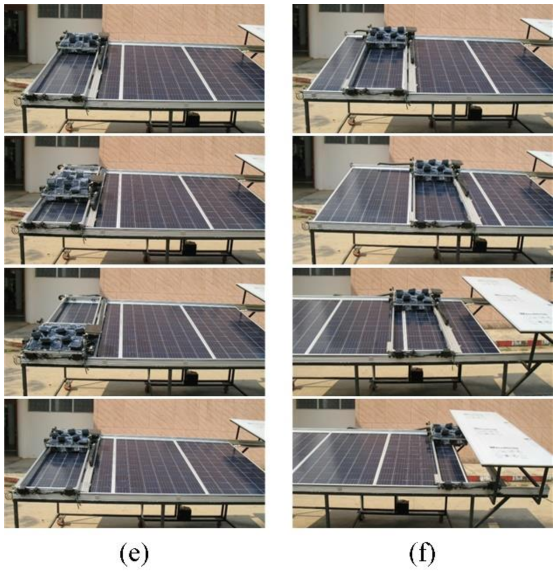


Fig. 6. Example of the robot operation (a) robot moves to the 1st part and starts its cleaning brush, (b) robot moves from the 2nd part to the 3rd part, (c) robot moves to the 4th part, (d) robot moves to the 5th part, (e) robot moves to the 6th part and finishes its cleaning task, (f) robot moves back to the docking station.

4. IMPLEMENTATION AND EVALUATION OF THE DEVELOPED SYSTEM

This section describes the test results of the proposed mobile robot system under real conditions. The purpose of which is to allow the developed mobile robot to effectively complete its tasks within an optimum amount of time, without experiencing any mistakes. The experiments have also been conducted to ensure that the solar panels employing the developed cleaning robot system offers better output performance when compared to the non-cleaned solar panels.

4.1. Implementation and Evaluation of proposed mobile robot system

In order to evaluate the capability of the developed robot system, several experimental scenarios have been conducted which focus on the effectiveness of the robot in both manual mode and autonomous mode. The robot has been evaluated and approved its ability in cleaning of the solar panels as it performs acceptable mobility during the operation. It can correctly start the procedure on the preset time and can effectively complete the cleaning operations around its working areas. The dusting brushes also turn and clean the dirt and dust through the cleaning process effectively. Table 1 presents the performance results for the robot movement test scenarios (consider Figures 4 and 6) while Table 2 displays time error between the preset time and the robot starting time. For the robot movement tests, each test is repeated ten times. The result of each test is then determined and found to be very reliable. That is primarily because the decision-making at each part is based on the robot position and its starting and goal positions, which are identical for each run under the same test scenario.

For the preset time test scenarios, each test is repeated four times, and the test results demonstrate that the developed cleaning robot system can suitably start working regarding the preset time with slight time errors. Additionally, the robot camera system, used to monitor the cleaning operation and detect damage of the solar panels, can work properly. It is connected to the internet and displays the live stream during the cleaning process through the developed web-application. The system can also be used for image capturing and video recording during the robot operation. All steaming data are effectively saved to the files which are accessible anytime and anywhere via the web-application.

Table 1. Performance measures of robot movement

Part	Defined position (m)	Robot position (m)	Avg. error (%)	Avg. time (s)	Avg. speed (m/s)
1st	1.30	1.29	1.15	10.65	0.07
2nd	1.80	1.79	0.83	6.84	0.07
3rd	2.30	2.27	1.26	6.89	0.07
4th	2.80	2.79	0.75	6.66	0.08
5th	3.30	3.28	0.67	6.59	0.08
6th	3.80	3.80	0.00	6.89	0.08

Table 2. Error between the preset time and the robot starting time

No.	Preset time	Robot starting time	Time error (mins)
1	6.00 a.m.	6.00 a.m.	0
2	6.30 a.m.	6.30 a.m.	0
3	7.00 a.m.	7.00 a.m.	0
4	7.30 a.m.	7.30 a.m.	0
5	8.00 a.m.	8.00 a.m.	0
6	8.15 a.m.	8.15 a.m.	0
7	8.30 a.m.	8.31 a.m.	1
8	8.45 a.m.	8.45 a.m.	0
9	9.00 a.m.	9.00 a.m.	0
10	10.00 a.m.	10.00 a.m.	0

4.2. Performance evaluation of solar panels

The performance of the solar panels has also been evaluated using the Hi-View brand polycrystalline solar panels; model HS-320P, with 320 Watts output power. The characteristics of such solar panels can be demonstrated in Figure 7 which displays the power – voltage curves of the tested solar panels in different dirt levels. For each curve, there is a point on the curve that the solar panel provides maximum output power to the load. This is identified as the maximum power point (MPP). It can be seen that the thickness of the dirt layer results in low performance of solar panels because the output power is dependent on dirt level as it obstructs solar radiation to incident on the module surface.

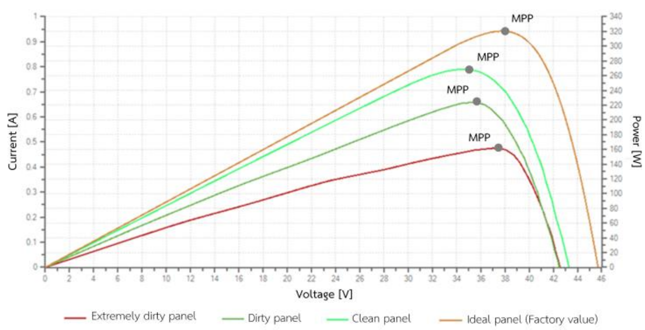


Fig. 7. Voltage–power characteristics of a tested solar module.

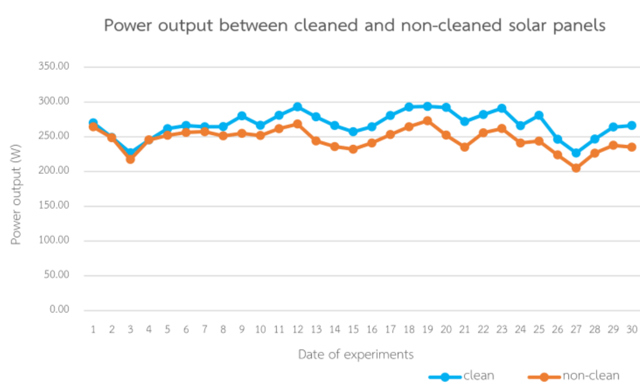


Fig. 8. Average power output between cleaned and non-cleaned solar panels in 30 days.

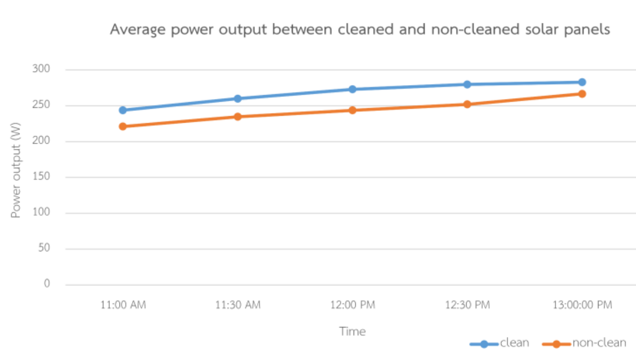


Fig. 9. Average power output between cleaned and non-cleaned solar panels during 11.00 a.m. – 13.00 p.m. over a 30-day period.

The experiments have been conducted using two modules of identical polycrystalline solar panels, each of which is tilted at 14.5 degrees to the ground facing eastwards. Both modules encountered the same ambient, wind speeds, temperatures, and insolation levels. Figure 8 demonstrates the average power output for 30 days from each solar module between 11:00 a.m. to 13:00 p.m. (local time, see Figure 9). It reveals that before using the proposed cleaning system, both solar modules show somewhat similar electric power output. However, after using the cleaning system regularly, there is an enhancement in the generated power output from the cleaned solar panels. For the time period selected, the average output of cleaned solar module is 268 Watts compared to 246 Watts from that of the uncleaned module. This represents approximately 8.8% more power from the cleaned module compared to the non-cleaned module over a 30-day period.

5. CONCLUSIONS

The dust and dirt accumulation decreases the solar radiation to incident on panels and sequentially reduces their generated power output of the solar modules. However, the cleaning technology can successfully improve the effectiveness of the electric power generation and can effectively enhance the solar panel durability. In this work, a mobile robot system for monitoring and cleaning of the solar panels has been designed and developed. It utilizes a robotic approach with the proper control architecture to undertake the robot operation. A series of tests have been conducted and experimental results demonstrate that the developed robot system can complete its tasks safely and effectively. Additionally, the performance of the solar panels is improved as the output power and efficiency rating of the panels is increased after the use of the developed system.

ACKNOWLEDGEMENTS

Authors would like to thank the Faculty of Engineering, Naresuan University, and the Center of Excellence on Energy Technology and Environment, Naresuan University, for their support and assistance with this study.

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