Design and Development of an Autonomous Raspberry PI Cleaning Robot For Photovoltaic Panels

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Abstract. This article presents a solution for the cleaning of solar panels using an autonomous robot based on a rail system and designed for highly inclined panels greater than 30 degrees. The accumulation of dirt and dust on solar panels can significantly reduce their performance. Therefore, the choice of designing this rail-based cleaning robot is based on the topographical nature in Tunisia, as well as other North Africa countries. Indeed, the photovoltaic panels inclination are typically between 20 to 35 degrees, unlike in Europe where the inclination varies between 10 to 20 degrees. Additionally, the climate in North African countries is characterized by significant temperature, humidity and dust which necessitates the use of pure water in the cleaning process. The robot is equipped with a rotating brush positioned on a mobile carriage that moves along the rails and move laterally across the panels allowing a thorough cleaning of the solar panel surfaces. We provide a detailed discussion of the robot's design, its movement mechanism, and how it optimizes solar energy production while contributing to environmental sustainability.

Keywords. Solar panels, photovoltaic panel, Cleaning Robot, IOT, Raspberry PI

1 INTRODUCTION

Fossil energy resources are rapidly depleting, underscoring the need to transition to alternative energy sources [1]. Among these alternatives, solar energy stands out as a promising option due to its renewability, abundance, and environmentally friendly nature [2]. However, the use of photovoltaic panels for electricity production requires regular maintenance to uphold their peak efficiency [3] Because the accumulated dirt on the surface of the panels reduces their performance. This requirement becomes more complex in regions with unique topographical and climatic conditions, such as Tunisia. Unlike their

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European counterparts, Tunisian solar installations demand steeper panel tilts 30° [4] to maximize energy capture, considering the specific climatic conditions. Tunisia's arid climate, characterized by high humidity [5] and persistent dust [6], exacerbates the need for regular solar panel maintenance. However, existing solar panel cleaning robots are primarily designed for lower tilt angles [7] and milder climates, rendering them ineffective in Tunisia's demanding environment. To address this challenge, we have developed an innovative solution: The Solar Panel Cleaning Robot based on a Rail System, seamlessly integrated with Internet of Thing (IoT) technology through the use of the Raspberry Pi board.

In this challenging context, it's crucial to explore various approaches for maintaining solar panels effectively. Generally, there are three solutions for solar panels cleaning systems. First, there are the manual cleaning solution illustrated in figure 1.a. This is the most common method for cleaning solar panels. Operators employ a variety of manual cleaning methods, such as brushing, rinsing, and using squeegees. These methods are effective at removing dirt, dust, and other debris from solar panels. However, they can be time-consuming and labor-intensive, especially for large solar panel arrays.

The second solution is the semi-automatic systems as presented in figure 1.b which involves specialized vehicles equipped with articulated arms, water tanks, pumps, hoses, and brushes [8]. The vehicle driver controls the articulated arm from the cab, allowing more efficient cleaning. The third cleaning solution, presented in figure 1.c, is the fully automatic cleaning system like in [9-10]. This system is designed with rubber tracks that enable them to move across solar panels. However, it's important to note that their functionality becomes limited on solar panels with a tilt of 30° or more due to design constraints. They feature rotating brushes for cleaning and are typically controlled remotely using a remote control or smartphone app. While effective on panels with lower tilts, they may not be suitable for the steeper panel angles often found in Tunisia.

These three distinct cleaning methods illustrate the challenges faced in cleaning solar panels and the need for innovative solutions. In the following sections, we will describe and design our cleaning system using IoT technology via the Raspberry Pi 4 in order to overcome the environments challenges above discussed.

2 METHODOLOGY

2.1 Design of the proposed cleaning robot

The proposed design of the proposed robot cleaning system is shown in Figure 2. The figure below illustrates all the mechanics components such as:

1: Handling drum, 2: Rotatable brush, 3: Trolley, 4: Rails, 5: Lateral transmission caster, 6: Box of the electric part
This design consists of a trolley that moves up and down on two rails guided by pairs of wheels mounted on each corner of the latter. Both wheels on each corner have axes perpendicular to each other, allowing the upper wheel to roll on the rail while the other wheel is inside the rail to prevent the trolley from deviating when moving. This movement of the trolley is ensured by a drum on which is wound a cable.

The robot also consists of a rotating brush that is carried by the trolley. It rotates using a small motor attached to the trolley. The brush ensures the cleaning of the panels with distilled water provided by solenoid valves placed on the rails and inner walls. The solar panels are tilted, allowing distilled water to flow naturally down.

The system is supported by two square aluminium tube rails. They are connected at both ends to form a frame. These two rails support the trolley (figure 3). They move laterally on the solar panels thanks to wheels (three wheels) located on each corner of the frame.

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**Fig. 2.** 3D implementation of the proposed cleaning system
2.2 Hardware Implementation

2.2.1 Mechanics analyzes

It is important to identify all forces acting on the system in order to properly evaluate the cable tension. The forces to consider in this case include:

- Weight of the trolley $P$: Gravitational force due to the mass of the cart, acting downwards.
- Cable tension $T$: Tension force exerted by the cable connecting the cart to the system structure. Identify the vertical and horizontal components of this force.
- Normal reaction force $R$: Force exerted by the surface of the solar panel on the brush, perpendicular to the surface.
- Friction force between the brush and the surface of the panel $F$: Friction force developed when the brush rotates and meets the surface of the panel (this force is assumed negligible).
- $x$: Inclination angle in Tunisia is equal to 30°

To analyze the forces acting on the trolley and brush of the automatic cleaning system of solar panels, it is necessary to apply the fundamental principle of statics. This principle states that for a system in equilibrium, the sum of forces in each direction must be zero:

- Following the direction $(O, x)$ (parallel to the panel):

  $$R_x + T_x + P_x = 0$$

  We have:

  $$R_x = 0$$

  (1)

  (2)

  and:

  $$P_x = -Psina$$, $T_x = Psina$ and $T_x = Psina$

- Following the direction $(O, y)$ (orthogonal to the panel):

  $$R_y + T_y + P_y = 0$$

  With:
\[ R_y = R, R = P \cos x; \land R = P \cos x \]  \hfill (5)

- **Numerical application:**

\[
T_x = 9.81 \times m_c h \times \sin 30; \text{ and } \{P = 9.81; x = 30\}
\]

\[
T_x = 9.81 \times 3.5 \times \sin 30 = 17.16 \text{ N}
\]

\[
R = 9.81 \times 3.5 \times \cos 30 = 29.73 \text{ N}
\]

### 2.2.2 Engine torque

We take the drum diameter to be 50 mm because the drum types in the market have the same diameter, therefore, its moment is:

\[
C_{Tam} = T \times R \]  \hfill (6)

**Where:**

- \( R \): is the drum radius
- \( C_{Tam} \): is the moment applied to the drum

Since the gear ratio between the drum pulley and the engine shaft is 1/3

\[
C_m = \frac{C_{Tam}}{3} \]  \hfill (7)

- **Numerical application:**

\[
C_{Tam} = 17.16 \times 0.025 = 0.429 \text{ Nm}
\]

\[
C_{m} = \frac{C_{Tam}}{3} = 0.143 \text{ Nm}
\]

Therefore, the selected motor (model-37gb31zy, 12 V-140 rpm) is redundant since its torque is equal to 3 Nm.

### 2.2.3 Electronics analysis

This system combines electrical and mechanical components to create an automated photovoltaic panel cleaning solution. Electrical design aims to provide appropriate power to the various motors, sensors and other electrical devices in the system. This involves choosing the right voltages, currents and powers, as well as sizing the appropriate cables and protective devices. On the other hand, mechanical design focuses on creating a strong and functional structure for the cleaning system.
2.2.4 Components and equipments

The electrical part of the system consists of connecting all the mechanical and electronics elements. This includes connecting motors, sensors, relays and other devices.

For our solution, we chose the Raspberry Pi 4 as the central microcontroller because it is powerful, affordable, versatile, and energy efficient. It also has support for IoT technologies, which will allow the robot to communicate with other devices and access cloud services.

Overall, the Raspberry Pi 4 is a good choice for the project because it is adaptable to other perspectives in the future. The flexibility and power of mini computer make it a good platform for developing new features and functionality for the robot. Figure 5 present all the electronic system. This configuration allowed us to control the cleaning of solar panels autonomously and efficiently.

![Electrical Design of the Proposed Cleaning System](image)

**Fig. 5.** Electrical design of the proposed cleaning system

With:
1) brush rotation motor
2) carcass motor for horizontal translation
3) carcass motor for horizontal translation
4) trolley motor for vertical translation
5) test plate
6) relay for brush rotation motor
7) relay for the carcass
8) relay for the carcass
9) relay for the trolley
10) relay for the solenoid valve
11) limit switches for the carcass and the carriage
12) Raspberry Pi 4
13) solenoid valve
14) power supply (Battery)

The relays are used to control the motors that allow the rotation of the brush and the vertical and horizontal translation of the trolley and the carcass. In addition, the Raspberry Pi controls the solenoid valve that must be powered by a battery. This solenoid valve is used to provide water to the brush for easy cleaning of solar panels. The board is also equipped
with limit sensors that are installed at each end of the trolley and carcass. These sensors send control signals to the board when the trolley or carcass reaches the end of its travel to prevent damage or accident.

2.3 Software implementation

The programming of the card is carried out using PyCharm software [11]. This involves writing the necessary computer code to control the different features of the cleaning system or it allows to define the behaviors and actions of the system according to the specific conditions encountered when cleaning the panels photovoltaic. In figure 6, we present a short of the python program.

```
import RPi.GPIO as GPIO
import time

# Configuration des broches GPIO pour chaque moteur
motor_horizontal = 1
motor_vertical = 2
motor_rotation = 3
sensor_top = 4
sensor_bottom = 5

GPIO.setmode(GPIO.BCM)
GPIO.setup(motor_horizontal, GPIO.OUT)
GPIO.setup(motor_vertical, GPIO.OUT)
GPIO.setup(motor_rotation, GPIO.OUT)
GPIO.setup(sensor_top, GPIO.IN, pull_up_down=GPIO.PUD_UP)
GPIO.setup(sensor_bottom, GPIO.IN, pull_up_down=GPIO.PUD_UP)

# Fonction pour faire avancer le chariot horizontalement d'une certaine distance
def move_horizontal(distance):
    speed = 50
    duration = 1
    speed = 100
    duration = 2
    else:
        speed = 150
        duration = 3
```

Fig. 6. Python code of the system

3 RESULT AND DISCUSSION

Our mechanical system has been subjected to rigorous tests that have confirmed its proper functioning. Key components, such as rails, trolleys and brushes, have demonstrated reliable performance and resistance to Tunisia’s demanding environmental conditions including dust, moisture and higher inclinations. Concerning the brush is made of carbon fiber specially designed to gently clean the surface of the solar panels without causing wear and scratches. Tests have confirmed the effectiveness of this brush by preserving the integrity of the panels while effectively removing dirt, dust and other contaminants.

To ensure the efficiency of the solar panel cleaning system while preserving their integrity, we have established a partnership with a company specializing in the manufacture of carbon fiber brushes. This collaboration gave us access to cutting-edge expertise in the design of brushes specifically adapted to cleaning solar panels. The carbon fiber brushes provided by this company have been carefully selected for their ability to remove contaminants without damaging the surface of the panels, ensuring optimal cleaning while preserving the long-term sustainability of solar installations.
The system has been rigorously tested to ensure its optimal operation, even on inclined panels at an angle of 30 degrees, in accordance with the topographical conditions of Tunisia. The drive wheels have demonstrated exceptional grip, avoiding unwanted slippage, while the friction between the drive wheels and the panel edge remains within acceptable limits. These results demonstrate the mechanical efficiency of our system, ensuring thorough cleaning of solar panels while maintaining adequate stability when moving on inclined surfaces.

Fig. 7. The system implementation

Electrical testing has confirmed the feasibility of our solar panel cleaning system which is designed to operate efficiently and autonomously. The simulations are carried out using the PROTEUS software and highlighted the performance of our system with regard to motor control and the management of the cleaning process steps.

Fig. 8. The electrics components

4 Conclusion

In a context of growing demand for electricity with the tendency to rely on renewable energy sources compared to fossil energies, solar energy appears to be a promising solution, respectful of the environment through reduction of polluting gas emissions. However, for solar panels to achieve their optimal efficiencies and effectively contribute to clean energy
production, regular maintenance is crucial. Our project concerns the design and implementation of a solar panel cleaning system, specifically adapted to the demanding climatic and topographical conditions in northern Africa, particularly in Tunisia. By using an autonomous mobile robot equipped with a carbon fiber brush to effectively clean solar panels while minimizing human intervention. The results of this work show that our solution offers a viable and economically advantageous alternative to traditional manual cleaning methods. By taking into account the angle of inclination of the solar panels, the humid climate and persistent dust, our system adapts well to these constraints and can serve as a model for other regions which face the same constraints. The integration of IoT technology using electronic boards like Raspberry and sensors allows remote control and automation of the proposed cleaning solution. For future work, we plan to continue developing our system by integrating a website for even more robust remote control. We will also think about improving the robot's power supply and changing the batteries with small solar panels and adding other sensors for fully automation of the solar panels cleaning system.

5 REFERENCES


