Data Article

Dataset for recognition of snail trails and hot spot failures in monocrystalline Si solar panels

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ABSTRACT

This article presents a dataset for thermal characterization of photovoltaic systems to identify snail trails and hot spot failures. This dataset has 277 thermographic aerial images that were acquired by a Zenmuse XT IR camera (7–13 µm wavelength) from a DJI Matrice 100 drone (quadcopter). Additionally, our dataset includes the next environmental measurements: temperature, wind speed, and irradiance. The experimental set up consisted in a photovoltaic array of 4 serial monocrystalline Si panels (string) and an electronic equipment emulating a real load. The conditions for images acquisition were established in a flight protocol in which we defined altitude, attitude, and weather conditions.

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1. Data

The dataset is generated to thermal characterize snail trails and hot spot failures on solar panels of “monocrystalline Si” and is composed of 277 thermography images. The specifications of the equipment used in this research are presented in Tables 1–6. The information about the dataset is

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summarized in Table 7. This dataset is organized in folders named according to the acquisition date. Folders between April 28th to May 4th contain two subfolders: “Images” and “Irradiance_Hour”; the subfolder “Images” has only images from the left panel. However, the folder of May 4th contain a third subfolder named: “Temperature_WindSpeed”. Folders between December 20th to January 11th contain three subfolders: “Images”, “Irradiance_Hour” and “Temperature_WindSpeed”; the subfolder “Images” has the subfolders “Panels_right” and “Panels_left” containing images labeled as illustrated in Fig. 1; “Panels_right” correspond to panels (1,2), “Panels_left” correspond to panels (3,4) of the Fig. 1(a). All raw data are presented with the “.csv” extension. The “Irradiance_Hour” subfolder contains a vector with information of the irradiance measurement, and the “Temperature_WindSpeed” sub-folder contains the wind speed measurement as well as the external and internal temperature.
For its part, in Fig. 1(a) the conditions of the cells for the 4 panels inspected are highlighted by colors; in Fig. 1(b) a real thermal image of the panels is shown. In Fig. 2 the image acquisition protocol used is schematized. In Fig. 3 the relative position between UAV and solar panels is illustrated.

Fig. 1. Four monocrystalline Si panels used for experiment: (a) scheme of panels with $9 \times 4$ cells in different conditions: hot spot (red) and snail trails (orange) failures, and sound cells (white), labeling of the panels, (b) Thermal image of the real solar panels.

2. Experimental design, materials, and methods

2.1. Materials

For acquisition of the database the next materials and equipment were needed:

- String of 4 ERDM Si monocrystalline solar panel connected in series, with 85 W maximum power for each panel (Table 1).
- B&K Precision 8514 electronic load at 1200 W maximum power, to emulate a real load behavior (Table 2).
- SP110 Apogee pyranometer, placed besides the solar panels string, to measure irradiance (Table 3).
- Ambient Weather SW-2090 weather station, placed at 3 m height from solar panels surface, to measure temperature and wind speed (Table 4).
- Zenmuse XT thermal camera, to acquire thermographic images (Table 5).

| Table 1 | Solar panel specifications. |
|---------|---------------------------|
| Number of cells | Dimensions (mm) | Weight (kg) | Open Circuit Voltage (V) | Short circuit current (A) |
| 36 | $1186 \times 551 \times 35$ | 9 | 21.78 | 5.13 |

| Table 2 | Electronic load specifications. |
|---------|-------------------------------|
| Resolution (mV/mA) | Minimum operating voltage (V) | Voltage Range (V) |
| 1/0.1 | 0.1 | 0−120 |

| Table 3 | Pyranometer specifications. |
|---------|---------------------------|
| Spectral range (nm) | Sensitivity ($mV \ W/m^2$) | Calibration Factor ($W/m^2 \ mV$) | Field of view (degrees) | Operation Environment (°C) |
| 360−1120 | 0.2 | 5 | 180 | −40 a 70 |
2.2. Method

An experimental protocol with 5 stages was designed to acquire the thermal images, as shown in Fig. 2.

2.2.1. STAGE 1

According to [2,3] the suggested irradiance level to acquire thermal images of photovoltaic systems (PV) should be at least 500 W/m². Hence, images acquisition was performed in sunny days since clouds decrease the irradiance levels and rain is a flight restriction for UAV. Images were captured between 10:00 to 11:30 and 13:00 to 14:00 hours, in order to use the maximum peak of irradiance levels (~ 800 W/m²) at Cali-Colombia. The interval between 11:30 to 13:00 hours was excluded to avoid shadows on the solar panels.

2.2.2. STAGE 2

After checking the weather conditions, we set up the value of voltage at the B&K Precision 8514 electronic load (constant voltage operation mode) to 80% of the open-circuit voltage delivered by the solar panel string, in order to approximate the operation point of maximum power [4,5].

2.2.3. STAGE 3

It is necessary to verify that environmental variables are within suitable ranges, thus:

- Matrice 100 drone, for aerial inspection of solar panels (Table 6).
- DJI Go application software, to visualize flight variables.

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**Table 4**
Weather station specifications.

| Measurement             | Range                        | Accuracy       | Resolution     |
|-------------------------|------------------------------|----------------|----------------|
| Outdoor Temperature     | -10 to 149 °F (-23.3 to 65 °C) | ± 2 °F (± 1.1 °C) | 0.1 °F (0.06 °C) |
| Indoor Temperature      | 32 to 140 °F (0 to 60 °C)    | ± 2 °F (± 1.1 °C) | 0.1 °F (0.06 °C) |
| Wind Direction          | 0-360°                       | ± 22.5°        | 22.5°          |
| Wind Speed              | 0 to 112 mph (0 to 180.3 km/h)| ± 2.2 mph (± 3.5 km/h) | 0.1 mph (0.16 km/h) |

**Table 5**
Thermal camera specifications.

| Pixels                  | Spectral Range (µm) | Angular vibration range | Thermal sensitivity (mK) | Weight (g) |
|-------------------------|---------------------|-------------------------|--------------------------|------------|
| 336x256                 | 7.5–13              | ± 0.03°                 | <50                      | 270        |

**Table 6**
UAV specifications.

| Type       | Hovering time full payload (min) | Max speed of Ascent (m/s) | Max speed of Descent (m/s) | Operating Temperature (°C) |
|------------|----------------------------------|---------------------------|---------------------------|----------------------------|
| Quadcopter | 20                               | 5                         | 4                         | -10 to 40                  |
• Wind speed at 3–5 m/s, to guarantee the precision specification in temperature measurement calculated by the thermal camera sensor in this type of experiments [6].
• Ambient temperature at a range of 26-30 °C, as suggested in [7].

2.2.4. STAGE 4
At this stage, irradiance measurement is verified to be within the range: 500–1000 W/m², as suggested in similar experiments [8].

2.2.5. STAGE 5
Once environmental conditions are verified to be adequate for thermographic inspection, the UAV was positioned horizontally 2.0 m far apart the lowest side of panels, and at 2.3–2.7 m height from the base of the panels, as indicated by Fig. 3. Aiming to do the camera IFOV (1.889 mrad) to cover 2 times the area of a panel cell, an ideal height up to 2.3 m was established, similar as done in [9], although they did not consider the IFOV camera. In consequence, the thermograms resolution (336 × 256 pixels) is high enough to get information about cells condition, unlike other similar works [10,11] where only global damages of panels can be detected because reported heights are greater than 20 m.

Additionally, inclination of the solar panels is 8°, which is possible due to geographical position of Cali, Colombia, close to equatorial line. This condition and a drone attitude (pitch angle) around 45° make the observation angle (between optical axis of camera and normal vector of the panel surface) be greater than 0° and smaller than 60° (45° approximately), in order to assure that emissivity variations are negligible [11].

Finally, because the drone is placed at a distance of up 2 m besides the panel, the cooling effect of the rotors blades of the UAV is negligible, and in consequence it is not taken into account.

2.3. Experimental design
We considered the images in dataset are spatially static because the drone was placed in fixed georeferenced coordinates, the pitch angle of the IR camera was constant, and height fluctuations with respect to the base of solar panels (2.3–2.7 m) were low, caused by gimbal vibrations or drone instability. However, acquisition was distributed in 7 experimental sessions, leading to important variations in irradiance, wind speed and ambient temperature, though all of them within allowable
ranges. This situation aimed to recreate a similar uncontrolled environment than that found at outdoor solar panel installations. Table 7 specifies the values of flight and environmental variables for each group of thermal images captured during independent experimental sessions.

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**Conflict of interest**

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.

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