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ASSESSMENT OF SOLAR PANEL CONTAMINATION VIA ITS IMAGE IN LIBYA CLIMATE

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Modern solar power plants are usually built in deserts, in conditions of lack of water and a lot of dust. Dustiness of solar panels leads to a decrease in their efficiency, and cleaning the panels from dust is an energy-consuming operation. The article discusses an approach to assessing the degree of contamination of a panel and making a decision about the need to clean it based on analysis of the panel image. An algorithm for making a cleaning decision is presented, a software application for assessing the degree of contamination of the panel is described, and the results of an experimental test of the created application are presented.

Keywords: *solar panel, dust deposition, solar energy, cleaning of panels, image processing*

Introduction

Modern solar power plants are several tens of square kilometers in size and contain millions of solar panels (SP). Such power plants are located mainly in desert areas, characterized by a lack of water sources and a large amount of dust. Dust on the surface of photovoltaic solar panels reduces their efficiency.

To assess the effect of solar panel dust on its output power, laboratory and field studies in Libyan conditions were carried out on the relative decrease in solar panel power depending on the density of dust on its surface. From the results obtained it follows that with a dust density of 5-20 grams/m^2, the output power is reduced by 5-10 % [1]. In other study, desert regions could lose power up to 80 % due to dust deposition [2].

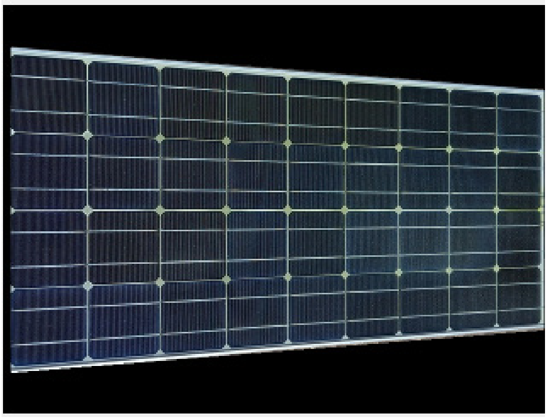
Manual cleaning of panels from dust can take considerable time and is very expensive; periodic (for example, daily) automated cleaning of panels using cleaning robots leads to high energy costs, premature degradation of panel surfaces, and also does not take into account contamination during sand storms.

So, there is a need to constantly monitor the contamination of the surfaces of solar panels in order to decide on their automated cleaning when the panel output power decreases due to contamination. The output power of PV panel is a random value due to random changes of sun radiation level on the PV panel surface. Different methods of PV panel contamination estimation were researched.

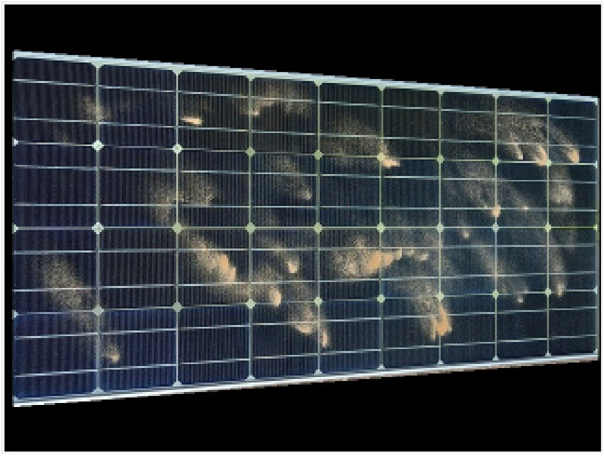
The study in Northern Australia demonstrates precise, inexpensive, and user-friendly techniques for assessing PV panel dusting and soiling. The proposed image processing algorithms, particularly the Image Matching algorithm, outperform the human eye in identifying dust color and texture [3]. Other study utilized statistical methods, image processing, and machine learning algorithms to intelligently monitor soiling state of solar panels, achieved a classification accuracy of 98.39 % [4]. While results in other study approved SolarQRNN, a probabilistic approach to quantifying using surveillance camera images, fares 51 % better in metrics evaluation on a solar panel soiling dataset than benchmark classification algorithms [5]. Additionally [6], confirm the possibility of using deep learning CNN based approach to detect dust on solar panel and predicted the power loss due to dust accumulation.

An assessment of the degree of contamination of a panel can be obtained by analyzing an image of dust on the panel surface. In this case, the image of the clean panel can be considered as the background, and the image of the dust as the foreground. To eliminate the influence of the background on the analysis result, you can calculate the difference between the images of clean and contaminated panels.

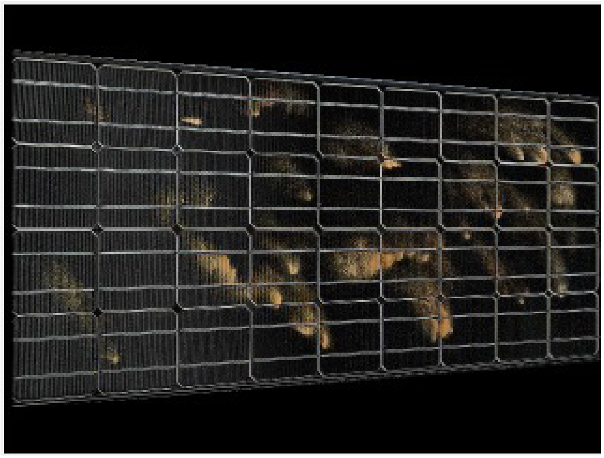
Images of clean panel and dusted panel and the difference of those two images are shown on the Figure 1.



a



b



c

Figure 1. Images of PV panel *a* – clean panel, *b* – dusted panel, *c* – Difference of clean and dusted panel images

Mathematical model of the dust image

The pixel values of the stored clean SP image are the sum of the pixel brightness values of the image itself and the noise.

$$P(x,y) = P_0(x,y)+n_0(x,y), \tag{1}$$

where $P_0(x,y)$ is the image of the clean panel at the time of shooting; $n_0(x,y)$ – noise at the time of shooting.

The pixel values of the current SP image in the absence of dust (or very small quantity of dust) can be represented as:

$$D(x,y) = P_1(x,y)+n_1(x,y), \tag{2}$$

where $P_1(x,y)$ is the image of the panel itself at the time of shooting; $n_1(x,y)$ – noise at the time of shooting.

If there is dust, the pixel values of the current SP image can be represented as:

$$D(x,y) = P_2(x,y)+n_2(x,y), \tag{3}$$

where $P_2(x,y)$ is the image of the dusted panel itself at the time of shooting; $n_2(x,y)$ – noise at the time of shooting.

Since the time of obtaining the stored and current SP images are different, the images themselves $P_0(x,y)$, $P_1(x,y)$ are different. These differences are due to differences in panel illumination at different times. The noise realizations $n_0(x,y)$, and $n_1(x,y)$ obtained at different times will also be different. Therefore, the difference image in the absence of dust on the surface of the panel (or with a small amount of it) can be represented in the form:

$$Dif_{10}(x,y) = P_1(x,y) - P_0(x,y) + n_1(x,y) - n_0(x,y) = \Delta P_{10}(x,y) + n_{10}(x,y). \tag{4}$$

If there is dust on the surface of the panel, the difference image can be represented as:

$$Dif_{20}(x,y) = P_2(x,y) - P_0(x,y) + n_2(x,y) - n_0(x,y) = \Delta P_{20}(x,y) + n_{20}(x,y) \tag{5}$$

Noise can be considered a random normally distributed value.

The brightness values of each pixel can also be considered a random normally distributed value. The probability density of the brightness of one image pixel can be represented as:

$$w(x_i) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\cdot\frac{(x_i-m_x)^2}{\sigma^2}}. \tag{6}$$

In accordance with formulas 4 and 5, the mathematical expectation mx will be different in the presence of dust and in its absence.

The set of pixel brightness values of the SP difference image can be considered a sample of a random process **X** = {x1, x1, … xn }where n is the number of image pixels. Considering the elements of this sample to be random independent normally distributed values, the multidimensional distribution density of the sample in the absence of dust can be represented as:

$$W(\mathbf{X}/H_0) = \prod_{k=1}^{n} w(x_k) = \prod_{k=1}^{n} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x_k-m_0)^2}{2\sigma^2}\right) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{1}{2\sigma^2}\sum_{k=1}^{n}(-(x_k-m_0)^2)\right). \tag{7}$$

Similarly, the multidimensional probability density of the difference image in the presence of dust can be represented as:

$$W(\mathbf{X}/H_1) = \prod_{k=1}^{n} w(x_k) = \prod_{k=1}^{n} \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x_k-m_1)^2}{2\sigma^2}\right) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(\frac{1}{2\sigma^2}\sum_{k=1}^{n}(-(x_k-m_1)^2)\right). \tag{8}$$

Consequently, the multidimensional probability density of a set of pixels of a difference image of the SP in the presence and absence of dust differs only in the average value of the pixel brightness.

Synthesis of a decision-making algorithm for cleaning SP

The task of making a decision about the dust content of a PN comes down to the task of testing a simple hypothesis H_1 that the average value of a set of random normally distributed variables is more than m_1 against the alternative H_0 that this parameter is less than m_1. A sufficient statistic for testing the hypothesis H_1 against the alternative H_0 can be any monotonic transformation of the likelihood ratio:

$$\Lambda = \ln \frac{W(\mathbf{X}/H_1)}{W(\mathbf{X}/H_0)}. \tag{9}$$

As a result of analyzing the difference image of the SP, one of two possible solutions is necessary: A_0 – there is no dust or A_1 – there is dust. The decision rule in this case is based on calculating the likelihood ratio [7] and has the form:

$$if\ \ \Lambda = \ln \frac{W(\mathbf{X}/H_1)}{W(\mathbf{X}/H_0)} \le \Lambda^*\ than\ \mathrm{A}_0 \text{ else } \mathrm{A}_1, \tag{10}$$

where Λ^* – decision threshold; $W(\mathbf{X}/H_0)$ – multi-dimensional probability density of the integral difference image in the presence of dust; $W(X/H_1)$ – multidimensional probability density of the integral difference image in the absence of dust.

The logarithm of the likelihood ratio in accordance with formulas 7 and 8 can be represented as:

$$\Lambda = \frac{1}{2\sigma^2}\sum_{k=1}^{n}(-(x_k - m_1)^2) - \frac{1}{2\sigma^2}\sum_{k=1}^{n}(-(x_k - m_0)^2)). \tag{11}$$

Or

$$\Lambda = \sum_{k=1}^{n} x_k - \frac{n(m_1 + m_0)}{2}. \tag{12}$$

The second term in formula 12 does not depend on the brightness values of the pixels and can be taken into account in choosing the threshold value Λ^*. Optimal processing of a difference image will be the summation of the brightness values of all its pixels. Therefore, to make a decision about the need to clean the SP, it is necessary to generate the sum of the brightness values of the difference between the images of the clean SP and the current SP image and compare it with the threshold Λ^*.

The decision-making algorithm on the need to clean the SP can be represented in the form

1. Obtain an image of the clean SP $P_0(x,y)$ and save it in memory (for example, as a file).
2. Periodically, with a certain time interval Δt, obtain the current image of the SP $P_1(x,y)$.
3. For each received current SP image, calculate the difference image

$$\mathrm{Dif}(x,y) = P_1(x,y) - P_0(x,y). \tag{13}$$

4. Calculate the sum of the brightness values of all pixels (total brightness) in the difference image

$$\Lambda = \sum_{k=1}^{n} x_k. \tag{14}$$

5. Make a decision on the need to clean the joint venture according to the rule

$$\text{if } \Lambda > \Lambda^* \text{ then start cleaning the SP} \tag{15}$$

To implement the above algorithm and evaluate the relationship between the sum of the brightness of all pixels and the solar panel contamination density, a software application was developed that allows you to perform the following operations:

1. Open images of a clean and dusty panel.
2. Calculate the difference image using formula (13) within a mask covering only the image of the panel itself.
3. Calculate the sum of brightnesses of all pixels of the difference image in each color channel.
4. Calculate the total brightnesses of all pixels using the formula:

$$TB = \sum_{i=1}^{3}\sum_{j=0}^{479}\sum_{k=0}^{639}\left(B_i(x_j, y_k)\right), \tag{16}$$

where $B_i(x_j,y_k)$ is the brightness level of the image pixel Dif(x,y) in the j-th column of the k-th row in the i-th color channel.

The appearance of the interface of the developed application is shown in the figure 2.

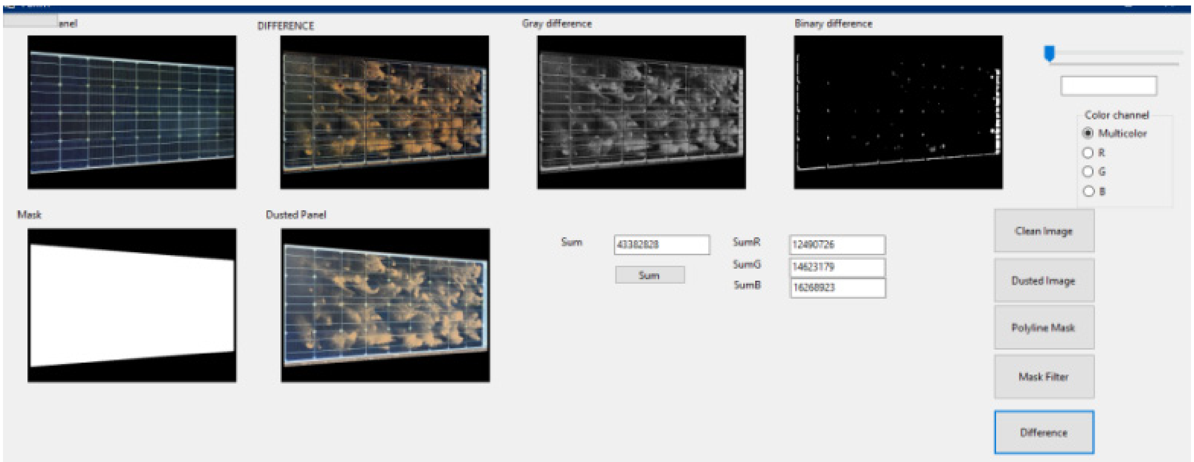


Figure 2. The software application interface

Experimental results

Using the created software, images of a solar panel obtained in the desert in Libya were examined at various densities of dust on its surface.

The experiments were carried out in the middle of the day at a solar radiation level of 910 W/m^2 using a Shell SQ85-P solar panel, the characteristics of which are given in Table 1.

Images of the panel and its power output values were obtained at dust densities of 0, 10, 20, 30 and 40 g/m^2. The resulting images were processed using the created software to obtain the total brightness of the dust image. The experimental results are presented in Table 2.

Table 1: The characteristics of solar panel.

PV Module Characteristics	Description
Module	Shell SQ85-P
Maximum Power (Pmax)	85 W
Rated Current	4.95A
Rated Voltage	17.2V
Open Circuit Voltage (Voc)	22.2V
Short Circuit Current (Isc)	5.45 A
Size	1.20*0.527m^2
STC	1000 W/M2 .25C.AM 1.5

Table 2. The output power and the total brightness of differences between the images

Dust (g/m^2)	SP image	P (W)	P (%)	P-loss (%)	Total brightness
0		67.50533	100	0	0
10		64.54068	95.60827	4.391733	36509535
20		60.92114	90.24641	9.753588	37419284
30		57.00919	84.45139	15.54861	42088638
40		56.51516	83.71955	16.28045	43382828

Figure 3 shows a graph of the dependence of solar panel power losses on dust density. Figure 4 shows a graph of the dependence of the total brightness of the difference image of the panel on the dust density.

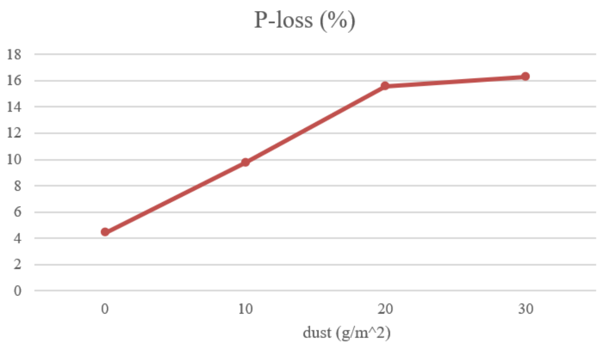


Figure 3. Graph of the dependence of solar panel power losses on dust density

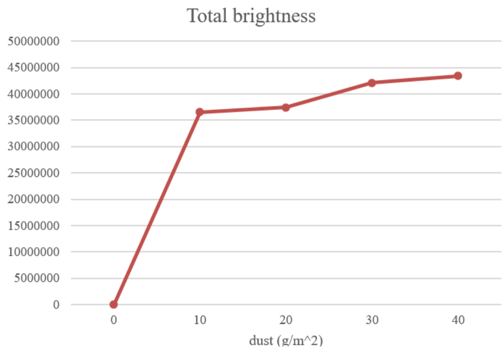


Figure 4. Graph of the dependence of total brightness on dust density

Conclusion

The degree of dustiness of a solar panel can be assessed by the difference between the images of a clean panel and a dusty one. An indicator of dustiness can be the total brightness of the difference image, which is sufficient statistics to make a decision about the need to clean the solar panel. The value of the total brightness of the difference image is proportional to the power loss of the solar battery when it becomes dusty.

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АЛЬБАГУШ А.А., КУПРИЯНОВ А.Б.

ОЦЕНКА ЗАГРЯЗНЕННОСТИ СОЛНЕЧНОЙ ПАНЕЛИ ПО ИЗОБРАЖЕНИЮ В КЛИМАТЕ ЛИВИИ

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Современные солнечные электростанции обычно строятся в пустынях, в условиях недостатка воды и большого количества пыли. Запыленность солнечных панелей приводит к снижению их эффективности, а очистка панелей от пыли является энергозатратной операцией. В статье рассматривается подход к оценке степени загрязненности панели и принятию решения о необходимости ее очистки на основе анализа изображения панели. Представлен алгоритм принятия решения об очистке, описано программное приложение для оценки степени загрязненности панели, а также приведены результаты экспериментальной проверки созданного приложения.

Ключевые слова: *солнечная панель, осаждение пыли, солнечная энергия, очистка панелей, обработка изображений*