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Hotspot Detection in Photovoltaic Module using Otsu Thresholding Method

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Abstract— **The growth of enthusiasm in developing power from sustainable resources has promoted to rise in the setting up of photovoltaic system. However, after the installations, it is still very low awareness of checking the PV module condition. Early hotspot detection is necessary to keep the PV working. Thermal imaging is still considered as common technique for diagnosing hotspot. This study proposes to develop a method to recognize hotspot in photovoltaic module thermal images using image processing technique. There are three essential process consisting of pre-processing, segmentation with Otsu thresholding method and identification. The data used contains 6 cropped images. The average accuracy results achieve 92.16%. This value shows that the proposed method is suitable to contribute the development of hotspot detection in PV monitoring system.**

Keywords— **Photovoltaic module, hotspot detection, thermal image, image processing**

I. INTRODUCTION

Today, Solar panel or photovoltaic module has been developed great concerned as compared among different types of sustainable resources. Current unpredicted development of photovoltaic installations led to boost request towards solar panel within the worldwide retail [1]. After the photovoltaic module have been set up, the problem now is that very low awareness of checking the PV module condition whether or not these modules are working at its ideal standard states. PV modules may be experienced some defects and failures that the user of PV cannot determine by eye. Defects or damages are difficult to figure out without skilled observation [2].

Generally, the cause of damages on the photovoltaic module initiates as a hotspot. A hotspot is a defect found in a photovoltaic module that disturb the typical operation of the PV module [3]. Hot spots are developed as a result of various motive. Cracks on module, failed solder, unintentional connections, shading, and soiling may form hot spots [4]. In [5] the active hot spot is detected using ac parameter characterization on photovoltaic. However, it is challenging to do in large-scale solar panel system. Another technique to identify hot spot is using thermography. Thermography or thermal image analysis technique is the great approach for identifying faulty of the photovoltaic module by reason of its quick and simple operation. In addition, this technique is an environmentally friendly and touchless evaluation method that able to determine thermal images in various classification of damage typical feature on the PV [1]. Thermal image analysis requires the implementation of image processing steps to interpret the image.

In image processing, segmentation was a crucial step because it had a considerable effect on the identification process. Thresholding is a common segmentation method that changes the grayscale image data to a binary format by finding the threshold value of the image. For an automatic finding of the threshold value, the Otsu method has been widely used in many applications. In development of eggs selection technology [6], Otsu thresholding method is used to classify egg into fertile and infertile. This research created a box with camera and lights which were managed by Arduino to detect an egg. In construction field, the study presents Otsu method for recognizing crack patterns in cement [7]. This method involves improvement of filtering operation using Sobel's filter. For medical imaging, brain tumor can be segmented with optimum threshold value used differential evolution algorithm set in with otsu method. It achieved accuracy of 94.73% [8]. For thermal image, Otsu thresholding has satisfactory result in segmenting the electrical equipment [9]. The image data is transformed to HSI color and detected the edge using Prewitt, Roberts and Sobel method. Lastly, Otsu image segmentation method is used to take hue region.

This work is aimed to create a system that is enable to detect hotspot area in photovoltaic module with thermal image data. The thermal images are downloaded from Journal Data in Brief Elsevier "Dataset for recognition of snail trails and hotspot failures in monocrystalline Si solar panels". The dataset was taken using the Zenmuse XT IR camera with wavelength of 7 - 13 µm for thermal description of PV module to recognize hot spot defects. Hotspot is identified using image processing technique. This technique consists of three steps, pre-processing, segmentation and identification. First, pre-processing changed the image to a grayscale. Second, segmentation transformed the grayscale into a binary image using Otsu thresholding method. According to previous studies, this method had good performance for segmenting image and had been successfully used for thermal image. Finally feature extraction extracted the pixel value from segmentation and used in identification result with bounding box around hotspot area of PV module. All of these steps were processed in MATLAB computational environment.

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This paper was arranged as follows: Section I shows the description of the background and the purpose of the research. It gives a little review of previous research. The dataset and proposed method were discussed in Section II. This section focuses on experimental research set up, describe the proposed method with pictures or figures and explain each part of the figures as the steps of proposed method. In Section III, the experiment results are presented and discussed about the obtained result by showing the evaluation method and image result. Finally, the conclusions were given in Section IV.

II. MATERIALS AND METHODS

A. *Data preparation*

The data was collected from "Dataset for recognition of snail trails and hotspot failures in monocrystalline Si solar panels" data article in Journal Data in Brief Elsevier. *Data in Brief* presents a solution for researchers to access datasets easily by publishing data articles. Data collection was completed by taking thermal images data of photovoltaic using IR camera Zenmuse XT [10]. Images were captured on sunny days from 10:00 to 11:30 and 13:00 to 14:00 to prevent shadows on the photovoltaic module. Raw thermal images data format is 336x256 pixels resolution with .jpg format. This study focused on 6 cropped images for the initial experiment to identify hot spot in solar panels by implementing image processing method.

B. *The proposed method*

The proposed method or system was built up for conducting transformation, segmentation, feature extraction, and classification of image data. It is an effective method for recognizing hotspot on module. It works in separating hot spot parts from background. Additionally, the system is able to give report regarding PV state. Condition of thermal data performs an important role for generating accurate and reliable evidence [1]. Image processing as proposed method consisted of three main steps. The three steps were pre-processing, segmentation, feature extraction and identification process. All steps were described in Fig. 1 as follow:

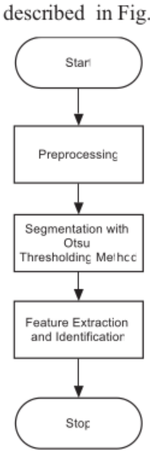

Fig. 1. The proposed system

1) *Pre-processing*

Pre-processing aims to enhance the feature of an image. It can provide benefits and accomplish problems that finally results in improved detection of local and global features. In this work, pre-processing in Fig.2 is started by transforming the RGB image into grayscale.

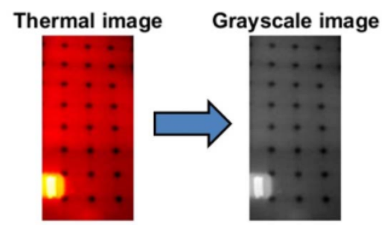

Fig. 2. Pre-processing Result.

Color images consists of more information than white and black images, so it can fill in more space in memory and add irrelevant complexity. Grayscale format is a great adjustment among subjective visual condition and relatively compact representation and storage [11]. This format is specified as monochrome image and encoded as a 2D array of pixels, where "black" equals to a pixel value of 0, "white" equals to a pixel value of 255, and varied tones of gray equals to transitional values between 0 and 255.

2) *Segmentation with Otsu thresholding method*

Image segmentation as in Fig. 3 is the important process in this method. The goal of this process is to divide an image in foreground and background. Image segmentation is a process of separating foreground from the background or clustering regions of pixels according to similarities in shape or colour in order to identify and characterize the object. Thresholding technique has been commonly applied in numerous image segmentations because of easy to implement and its simplicity. It converts a graylevel image to a binary format based on threshold values [12]. In checking the thermal circumstance of photovoltaic modules, thresholding method is a highly beneficial technique for isolating the hot area (foreground) from its background. In this study, the potential heated abnormalities on the modules can be found by Otsu method.

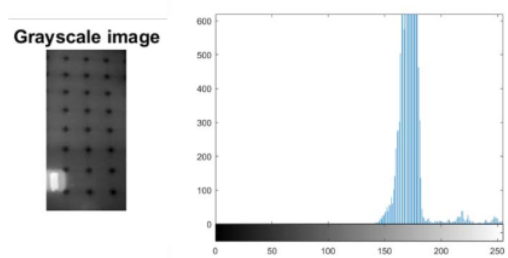

Fig. 3. Histogram of grayscale image

Otsu thresholding method was initiated by Nobuyuki Otsu. It is applied to obtain the threshold value automatically. The concept of otsu method is a discriminant analysis approach that finds out a variable which will categorize into some classes. The steps of Otsu were described as follows:

- Step 1 : Calculate the histogram values.

Otsu needs to computing the histogram of grayscale image before operating. Image histogram in Fig. 3 is chart representation of the distribution of intensities in an indexed grayscale image. It shows how many times each intensity or pixel value in image occurs. From pixel values of histogram, the ideal threshold value is achieved by verifying the highest between-class variance (BCV) of the pixels of background and foreground.

- Step 2 : Calcuate the probability intensity value

  The pixels of a grayscale image data be expressed by gray range L [1, 2, …, L]. The potential of every pixel at the i stage was displayed in (1), with n_i indicates the pixel count i and the pixel intensity be represented in N with $N = n_1+n_2+\ldots+n_L$ [13] as in (1) as follows.

$$p_i = \frac{n_i}{N}, \qquad p_i \geq 0, \sum_{i=1}^{L} p_i = 1 \qquad (1)$$

- Step 3 : Calculate the class occurence and class mean levels

  Divide the pixels into two groups C_0 as background and C_1 as foreground by a threshold at level k; C_0 shows pixels with levels [1, , k], and C_1 presents pixels with levels [k + 1, … , L]. Then the potentials of class occurrence in (2) and (3) and the class mean levels in (3) and (4), respectively, are as follows.

$$\omega_0 = \Pr(C_0) = \sum_{i=1}^{k} p_i \qquad (2)$$

$$\omega_1 = \Pr(C_1) = \sum_{i=k+1}^{L} p_i \qquad (3)$$

and

$$\mu_0 = \sum_{i=1}^{k} i \, Pr(i|C_0) = \sum_{i=1}^{k} i p_i/\omega_0 \qquad (4)$$

$$\mu_1 = \sum_{i=k+1}^{L} i \, Pr(i|C_1) = \sum_{i=k+1}^{L} i p_i/\omega_1 \qquad (5)$$

- Step 4 : Compute between class variance

  The between-class variance (σ_B^2) determines the otsu which is displayed in (6).

$$\sigma_B^2 = \omega_0 \omega_1 (\mu_1 - \mu_0)^2 \qquad (6)$$

- Step 5 : Find the maximum between class variance

  Finally, the optimal threshold k^* as in (7) is expressed as follows.

$$\sigma_B^2(k^*) = \max_{1 \leq k < L} \sigma_B^2(k) \qquad (7)$$

Thresholding operation was shown in (8). If the grayscale image is $I(x,y)$, the binary image $g(x,y)$ is defined in (8) as follows.

$$g(x,y) = \begin{cases} 1 \text{ if } I(x,y) \geq th \\ 0 \text{ if } I(x,y) < th \end{cases} \qquad (8)$$

where th is the thresholding value from the optimal threshold k*, $g(x,y)$ = 1 for image elements of foreground or hotspot and $g(x,y)$ = 0 for image elements of background. Accurate selection of threshold is important for profitable threshold segmentation [14]. The result of this operation is displayed in Fig. 4 as follows.

Fig. 4. Segmentation Result.

Fig. 4 displays the output of Otsu method for converting grayscale format to a binary format. The goal of this binarization is to show pixels that indicate foreground areas with a single intensity and background area with different intensities. It is noticed that this method has segmented the given data with threshold value of 198.

3) Feature Extraction and Identification

After doing segmentation, feature extraction is done to get the information about the regions in the segmented image. Feature extraction is the necessary step to extract the color feature from segmentation result. The segmentation result is the binary image where hotspot region color is white and equals to pixel value of 1 and background image color is black and equals to pixel value of 0. These values were extracted for identification step. Figure 5 shows the result of Feature Extraction and Identification process.

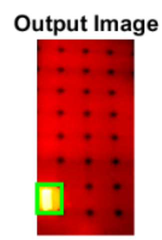

Fig. 5. Detection result.

Output process in Figure 5 displays detection result with bounding box around hotspot area of PV module. The bounding box may be a rectangular box which will be discovered by the x and y axis coordinates within the upper-left corner and therefore the x and y axis coordinates within the lower-right corner of the rectangle. In object identification or detection, bounding box is usually applied in showing the target location. In this study, the hotspot area is the target and it is located based on pixel value. If the regions' pixel value is 1 then the system draws bounding box around them.

III. Result and Discussion

The proposed method has been evaluated by implementing quantitative comparison. The proposed method was tested and evaluated 5 cropped photovoltaic images from data article "Dataset for recognition of snail trails and hotspot failures in monocrystalline Si solar panels" of Journal Data in Brief Elsevier. The image segmentation and evaluation were processed in MATLAB computational environment. Evaluation process were conducted by computing the accuracy as formulated in (9).

$$accuracy = \frac{TP + TN}{TP + TN + FP + FN} \qquad (9)$$

Accuracy in this study can be described as for how good the segmentation method segments the background and foreground (hotspot). It is a collection of true segmented pixels over the total number of pixels [15]. The understanding of True Positive (*TP*), True Negative (*TN*), False Positive (*FP*), and False Negative (*FN*) are crucial in this evaluation. Table 1 shows these variables as the confusion matrix. A confusion or error matrix is a table that shows correspondence between the system result and a reference image (ground truth). It is used as the quantitative method for defining image segmentation accuracy.

TABLE I. CONFUSION MATRIX

System Results	Reference Image (Ground Truth)	
	Hotspot	***Background***
Hotspot	TP	FP
Background	FN	TN

- *TP* (True Positive) is the Hotspot pixel that segmented as hotspot in system.
- *FP* (False Positive) is the Background that pixel segmented as hotspot in system
- *FN* (False Negative) is Hotspot pixel that segmented as background in system
- *TN* (True Negative) is Background pixel that segmented as background system.

Table 2 shows the experimental result of segmentation system. Ground truth is the manually segmented reference image which is used to evaluate Otsu method by comparing it with the obtained Otsu segmented image. This evaluation approach is called supervised evaluation. The advantage of this supervised approach is available immediate observation between the pixel of reference image (ground truth) and pixel of Otsu segmented image which could generate great accuracy of the evaluation [16]. The experimental results achieved accuracy from images no. 1 to 6 of 100%, 99%, 63%, 97%, 99% and 95% respectively. This result shows good performance system with average accuracy of 92.16%. However, there are still quite high noise in image no. 3. So the system needs to remove noise by applying image enhancement process such as filtering and morphological operation before it is used for segmentation and detection.

TABLE II. EXPERIMENTAL RESULT

No.	**Grayscale image**	**Ground Truth**	**Otsu Method**	**Accuracy**
1.	 **DJI_0804.jpg**			100%
2.	 **DJI_0035.jpg**			99%
3.	 **DJI_0898.jpg**			63%
4.	 **DJI_0147.jpg**			97%
5.	 **DJI_0811.jpg**			99%
6.	 **DJI_0634.jpg**			95%
Average Accuracy				92.16%

IV. Conclusion

This paper aims to detect hotspot area on photovoltaic module. This study shows segmentation method of Otsu thresholding method for segmenting grayscale thermal image and provides the initial experiments in an ongoing research. It performs an important role in pre-identification to determine the information of thermal image features. The proposed method have evaluated 6 cropped photovoltaic thermal images. For evaluation results, the proposed method obtains quite high average accuracy of 92.16% It shows that this work is successful in segmenting the hotspot. Besides the benefits of this study, there are limitations needed an improvement on the further research studies in order to develop PV monitoring system.

V. ACKNOWLEDGEMENT

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