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Submission date: 25-Jan-2022 05:20PM (UTC+0700)

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A New Approach for Hot Spot Solar Cell Detection based on Multi-level Otsu Algorithm

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Abstract— Hotspot cells can harm the photovoltaic modules because the cells spend or use up energy instead of generating energy. Therefore, the image processing method is applied to allow the hot spot detection automatically. This paper evaluates Multi-level Otsu based approach for image processing to segment and detect hot spot solar photovoltaic cell of photovoltaic module using thermal images. The methodology was completed by performing image segmentation, image binarization, and noise removal with morphological operation. This proposed method was tested by using ten thermal images and evaluated by measuring the accuracy of each image with different threshold level. The highest accuracy achieved 97.22% from thermal image DJI_0898, DJI_0911 and DJI_0918.

Keywords— photovoltaic cell, thermal image, hotspot detection, Multilevel Otsu

I. INTRODUCTION

The usage of renewable energy resources is started from the fact that nonrenewable energy is not a great recommendation to the worldwide energy request. Energy from the sun has improved into an acceptable renewable energy resource supported by technological advancement [1]. This energy is from the sunlight and converted into electricity using a photovoltaic or solar panel system. It is the popular system recently offered. Despite the evidence that is very reliable and efficient, some causes critically harm the photovoltaic system's performance from the outside. The main causes are defects on the surface of solar panels, full or partial shading, and soiling. An optimal solar panel system is needed to prevent these issues using a monitoring system.

Recently, photovoltaic monitoring systems are developed using thermography technology which has been widely used for electrical equipment monitoring and fault diagnosis [2]. Infrared thermography is commonly applied in solar panel systems to diagnose PV module issues based on the thermal features. This is a technique using infrared energy that is not visible to the naked eye, emitted by an object and then converted into a thermal image visually using a thermal imaging camera [3]. For this case, a thermal imaging camera is used to identify the high-temperature area, which is indicated as an overheated cell or known as a hotspot. Hotspots may damage the solar panel because the cells consume energy instead of producing energy. Therefore, the

image processing method is implemented to provide automatic recognition of hotspots and explore the evaluation techniques.

Thermal image processing is adopted to determine the possible defect region by identifying hotspots in solar panel systems. This method's primary concept is that most elements tend to display an increase in temperature while improperly [3]. This image processing enables to monitor the heat, which can be used to contribute to locating the potential problem area from the image. Appropriate algorithms are performed in this method to help the detection process.

The algorithms or several steps are needed to be executed for completing the identification process as researched by Alfaro-Mejia et. al [4]. This study introduced two techniques of segmentation step for Photovoltaic thermal image: active tours level-set method (ACM LS) and filtering by area. These techniques gain the contours of the solar panels and the edges are processed using Morphological operations. Histogram transform is applied to locate lines in the thermal image. The extraction of the region of interest is evaluated from the Dice similarity coefficient (DSC), Intersection over Union (IoU), and recall segmentation metrics. However, this research has not yet reached the detection of hotspots on solar panels.

Other related research for the photovoltaic thermal image is organized by Luis E. Montanez et al. [5]. The study implemented image enhancement by improving contrast followed by Dynamic Histogram Equalization (DHE) and applying the Equalization of Adaptive Limited Contrast Histogram (CLAHE). This study also adopted the thresholding technique and designed a GUI, which can be regarded as a good tool for thermographic analysis of photovoltaic modules. Nonetheless, the percentage of accuracy of this method was not discussed.

For detecting the hotspot on PV Module, a previous study applied the bi-level thresholding technique in the segmentation process to split the hotspot or foreground from the background using the Otsu thresholding method [6]. It changes a grayscale into a binary image depend on a threshold value. The raw data are taken from the dataset [7] and achieved 92.16% accuracy. However, this research evaluated only six cropped images as the initial experiment, and the system does not yet utilize image enhancement such as filtering and morphological operations to reduce noise.

Therefore, in this paper, a new approach for hotspot detection is proposed. The proposed method is based on the Multilevel Thresholding Otsu algorithm for segmentation combined with the filtering and morphological operation. This technique is used because it can provide segmentation accurately based on [8] to facilitate the improvement of the segmentation and detection process. The rest of the paper is structured as follows. Section 2 provides an overview of infrared thermography. Section 3 gives the proposed methodology to identify the hotspot cell in PV modules. In Section 4, results and discussion are presented. Finally, conclusion statements are delivered in Section 5.

II. INFRARED THERMOGRAPHY

Infrared thermography is similarly named infrared imaging or thermal imaging as it applies infrared or electromagnetic radiance beamed originating from the heat [3]. Infrared imaging is typically determined as a non-destructive system for operating in the verification phase. Today, economical, safe, and non-contact type infrared thermographic surveillance technique is popular for defect analysis and observation. Any object above absolute zero temperature radiates heat energy in infrared form. The amount of heat energy transmitted by an object increases with temperature. Therefore, thermography enables people to perceive temperature variations using a thermal imaging camera.

A thermal camera can observe radiation in the infrared range of the electromagnetic spectrum. Hot area or foreground be noticed well around cooler area or background when observed through this device. It creates images, called thermograms or thermal images. Throughout the investigation and evaluation of the thermal image, an essential task performs objective aspects related to the object's emissivity and subjective elements—human perception of visual orientation. Unfortunately, the thermal camera's ideal specification setting does not ensure accurate thermal image identification. Therefore, the image processing method is applied. This method's fundamental goal is to upgrade the image's quality because the images captured were more relevant for a specific utilization [9]. Inequality among apparent thermal image cause that adjustment of image processing method is more complicated and requires particular recommendation.

Image processing methods are being implemented to the thermal image to diagnose the fault. There are two necessary steps of this method, i.e., image enhancement and image segmentation [10]. These steps can be adapted for recognizing faults or defects in Solar cells because the common defects impact their thermal behavior. This method is the simplest way to identify the hotspot within the photovoltaic or solar panel infrared thermographic image [2]. Infrared thermographic images of Solar Panel systems can be taken using unmanned aerial vehicles (UAVs), which fly over a photovoltaic module capturing images. When exploring thermographic images, it is crucial to consider the angle of observation because the PV module's front glass may reflect the daylight it accepts, reported as heat energy by thermal cameras [1].

III. METHODOLOGY

A. Image Segmentation with Multilevel Otsu Thresholding

Among all existing segmentation techniques, thresholding is the most common and popular method because of its simplicity, robustness, and accuracy [11]. Thresholding is a segmentation procedure that divides or separates one image into several regions based on the same color or grey level intensity. The thresholding method can be divided into two types, namely bi-level thresholding and multilevel thresholding. Bi-level is a type of simple thresholding that classifies image pixels into two groups, the first consists of pixels below the threshold limit, and the second is the rest. This method is not able to handle images that have a very slight difference in grayscale. Therefore, multilevel thresholding is needed to divide the degree of grayness into the appropriate sub-regions.

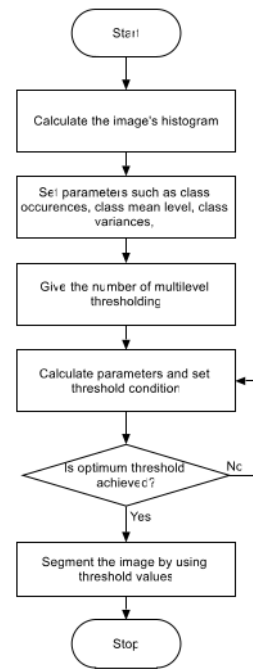


Fig. 1. Flowchart of multilevel thresholding

Multilevel image thresholding is a process that split the degree of gray in an image into clear regions based on several points or threshold values. Multilevel thresholding separates pixels into classes or groups. Pixels in the same class will have a degree of grayscale within a specific range, which is obtained from several thresholds.

For multi-level Otsu thresholding, the grayscale image $G(x, y)$ is converted to a segmented image $S(x, y)$ by setting threshold $T = \{t_1, t_2, \dots, t_n, t_k\}$ which is consist of the amount k thresholds. The observed histogram is denoted with n_i and the total number of pixels $N = n_1 + n_2 + \dots + n_m$, where L is the number of histogram's gray values. The histogram is assigned as a distribution of probability, as shown in (1) as follows.

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

The pixels of image are segmented to a proper number of k levels of preferred thresholds. The image is then sectioned into $k+1$ levels or classes which is denoted by $C_0 = \{0, 1, \dots, t_1\}$, \dots , $C_n = \{t_n + 1, t_n + 2, \dots, t_{n+1}\}$, \dots and $C_k = \{t_k + 1, t_k + 2, \dots, L-1\}$. Consequently, the class occurrences (w_n), the class-mean levels (μ_n) and the class variances (σ_n^2) respectively are computed as in (2), (3), and (4) as follows.

$$w_n = \sum_{i=t_{n+1}}^{t_{n+1}} p_i \quad (2)$$

$$\mu_n = \frac{\sum_{i=t_{n+1}}^{t_{n+1}} ip_i}{w_n} \quad (3)$$

$$\sigma_n^2 = \frac{\sum_{i=t_{n+1}}^{t_{n+1}} P_i (i - \mu_n)^2}{w_n} \quad (4)$$

The within-class variance (σ_{wc}^2) of all segmented classes of pixels is given as (5) as follows.

$$\sigma_{wc}^2 = \sum_{n=0}^k w_n \sigma_n^2 \quad (5)$$

The between-class variance, measures the separability among all classes (6) as follows.

$$\sigma_{bc}^2(k_1, k_2, \dots, k_L) = \sum_{n=0}^k w_n (\mu_n - \mu_T)^2 \quad (6)$$

the optimal threshold k^* that maximizes σ_{bc}^2 is stated as (7). The segmentation result of multilevel Otsu thresholding is shown in Fig. 2.

$$\sigma_{bc}^2(k_1^*, k_2^*, \dots, k_L^*) = \max_{1 \leq k_1 < \dots < k_L < L} \sigma_{bc}^2(k_1, k_2, \dots, k_L) \quad (7)$$

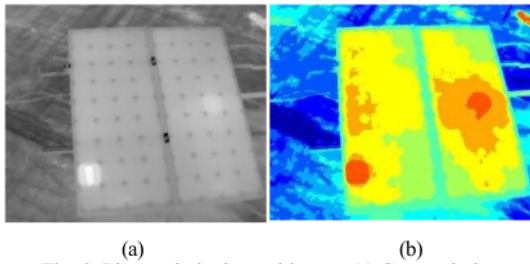


Fig. 2. Photovoltaic thermal image. (a) Grayscale image, (b) Segmented image

In the grayscale thermal image (Fig.2 a), the brighter area indicates higher temperature [3]. In this image, the resulting thresholds consist of 9 values. They are 28, 74, 89, 103, 121, 146, 168, 182, and 200, so that the resulting segmentation

consists of 10 areas or classes labelled with RGB color, as seen in figure 2 (b). It shows that the color of higher temperature is close to red, and the cooler region is near to blue.

B. Image Binarization and Noise Removal with Morphological Operation

The binarization process is a process to produce a binary image or black and white image according to a predetermined threshold value. It is done by taking the most significant threshold value from multilevel otsu as the binarization threshold value. This binarization can be defined in (8), where th biggest threshold value from previous step.

$$b(x, y) = \begin{cases} 1 & \text{if } G(x, y) \geq th \\ 0 & \text{if } G(x, y) < th \end{cases} \quad (8)$$

The objective of this binarization is to display the foreground and background area. It is noticed that this method has segmented the given image with threshold value of 200. After binarizing the image, it can be seen in Fig. 3 (a) that not all white from the resulting binary image is the foreground. Therefore, the part of the pixel that is not the foreground is the noise that needs to be removed to produce good accuracy in the detection process.

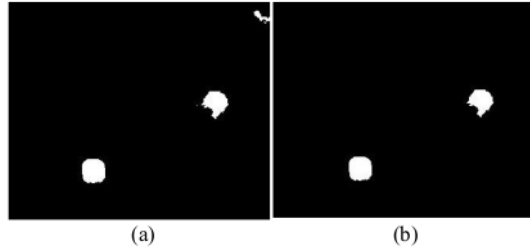
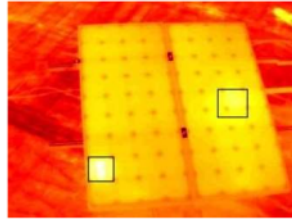


Fig. 3. Binary image. (a) Before morphological area opening, (b) After morphological opening

The typical binary image operations are called morphological operations since they change the underlying binary objects' shape. Morphological operations are image processing techniques based on the condition of segments or regions in the image. Because it is focused on the object's shape, this operation is usually applied to binary images. In this study, the morphological area opening was used to erase or remove a particular area not included in the foreground.

IV. RESULT AND DISCUSSION

This study used thermal images from downloadable data of Journal Data in Brief Elsevier "Dataset for recognition of snail trails and hotspot failures in monocrystalline Si solar panels." The result or output of the methodology is shown in Figure 4. In this approach, the hotspot cell is detected based on pixel value from the binarization step. The result displays the thermal image with hot colormap and bounding box around hotspot cell.



15 Fig. 4. Detection result

In this paper, accuracy is defined as the percentage of the correctness in detecting hot spot and non-hotspot cells. This value is determined by comparing the number of correct detection cells with the total cell.

$$ACC = \frac{\text{Correct Detection Cells}}{\text{Total Cell}} * 100\% \quad (9)$$

Ten images were tested in this study with different k levels of threshold and evaluated the accuracy. Table I shows the accuracy value for different k levels using the proposed method.

TABLE I. Detection Accuracy with different k level

Image	Accuracy (%)		
	k level 7	k level 8	k level 9
DJI_0804	93.05	93.05	93.05
DJI_0807	93.05	93.05	93.05
DJI_0811	94.44	93.05	93.05
DJI_0816	95.83	93.05	93.05
DJI_0898	86.11	97.22	97.22
DJI_0911	83.33	97.22	97.22
DJI_0918	83.33	94.44	97.22
DJI_0008	58.33	75	91.66
DJI_0100	58.33	75	91.66
DJI_0114	58.33	58.33	70.83
Average Accuracy (%)	80.42	86.94	91.81

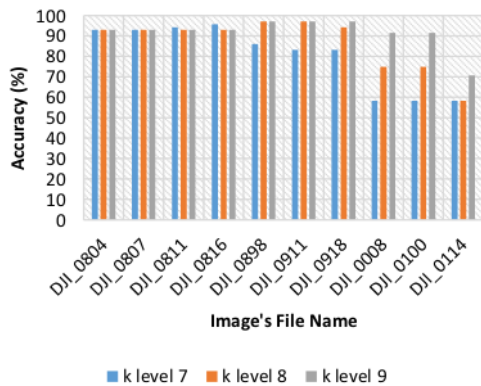


Fig. 5 Accuracy of each image

As shown in Figure 5, the chart shows the detection accuracy from ten thermal images. Three colours represent each image: blue for k level 7, orange for k level 8, and gray for k level 9. Thermal images DJI_0898, DJI_0911 and DJI_0918 have the highest accuracy for k level 9 at 97.22%. The lowest accuracy is given by thermal images DJI_0114 with 58.33% for k level 7 and k level 8. This is because the PV module's front glass captured using unmanned aerial vehicles reflects the sunlight and reported as heat energy by the thermal camera. So the acquisition or input image DJI_0114 has the wrong interpretation resulting in the less precise segmented image, as shown in Fig. 6.

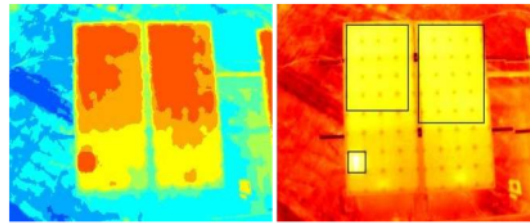


Fig. 6. The less precise segmented image and detection result of DJI_0114

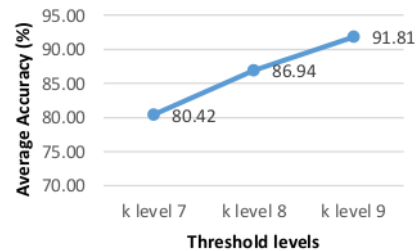


Fig. 7. Comparison of average accuracy

Accuracy measurement of k level 7, k level 8, and k level 9 in Table I produces an average accuracy of 80.42%, 86.94%, and 91.81%, respectively, for the proposed method. It can also be seen in Fig. 7 that the average accuracy value increases with the increase in the k threshold level. Thus, among the k level values that have been tested, k level 9 of the Multilevel Otsu algorithm gives the most effective detection result.

V. CONCLUSION

This paper proposed a new approach, namely Multilevel Otsu Thresholding, to segment the photovoltaic Module's thermal images and detected the hotspot cell. It determined the detection accuracy by comparing the number of correct detection cells and the PV's total cells. The result showed that the more k level of Multilevel Otsu is used, the more accurate detection is. Also, it displayed that image acquisition from the thermal camera is the crucial step to produce better accuracy. This research will be developed specifically to enhance the thermal image with contrast or smoothing filter and analyse other evaluation metrics.

VI. ACKNOWLEDGEMENT

This research is granted by the National Ministry of Education and Culture of Indonesia under "Program Hibah PMDSU UNHAS-DIKTI" 2021.

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