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Image Processing Based Hot-Spot Detection on Photovoltaic Panels

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Abstract: Photovoltaic systems have become more popular as people become more interested in developing energy from renewable resources. Even after the installations, however, there is still a lack of understanding about the importance of inspecting the condition of the PV modules. To keep the PV running, early hot-spot detection is required. For detecting hot-spots, thermal imaging is still a popular technique. This research proposes to develop a method for detecting hot-spots in thermal images of photovoltaic modules using artificial intelligence techniques. Pre-processing, segmentation with an Artificial Neural Network and identification are the three main processes. The proposed method appears to be a good choice for improving hot-spot detection in PV monitoring systems, according to the results of the experiments.

Keywords: *PV monitoring system, Image segmentation, Artificial Neural Network (ANN), JSEG Algorithm, Hot-spot.*

1. Introduction:

When compared to other types of sustainable resources, solar panels, also known as photovoltaic modules, have received a lot of attention recently. The current unanticipated growth of PV installations has resulted in an increase in demand for solar panels in the global retail market [1]. After the photovoltaic modules have been installed, the problem now is that there is a lack of awareness about checking the condition of the PV modules to see if they are operating at their optimal levels. PV modules may have defects or failures that are not visible to the PV user. Without expert observation, determining defects or damages is difficult [2].

In most cases, a hot-spot is the source of photovoltaic module damage. A hot-spot is a flaw in a photovoltaic module that prevents it from operating normally [3]. Hot-spots form as effect of a variety of factors like cracked modules, solder failure, connections with unintentionally, soiling and partial shading [4]. The photovoltaic ac parameter characteristics are used to detect the active hot spot in [5], but this is difficult in a large-scale solar PV system. Thermography is an additional method for locating hot spots. Thermal image analysis, also known as thermography, is an excellent method for detecting photovoltaic module faults due to its simple and quick operation. Furthermore, this method is a non-contact, eco-friendly evaluation method capable of determining thermal images in various PV damage classifications. The image processing is used to analyze the thermal image in order to interpret the image.

Thermal imaging cameras are most commonly used to check for hot-spots in PV modules, but not entirely accurate techniques for diagnosing PV hot-spots have been developed in recent years. In [6] projected a data-driven characteristic extraction technique for analyzing photovoltaic hotspots. The main drawback of this technique is that all the results were obtained using only shaded PV cells. When compared to actual hot-spot PV modules, many researches show that simply applying shade does not always associate with the total current and voltage loss. Furthermore, because this technique necessitates the addition of a capacitive load to the PV module, it is physically challenging to implement. In [7] proposed a method for identifying PV hotspots based on the power-voltage curve characteristics of PV modules. Only stand-alone photovoltaic modules can be used with this method. It only determines whether the PV modules have hotspots, not their nature or "type." In [8] proposed a appropriate algorithm for identifying PV hotspots based on an analysis of 2000 photovoltaic modules. This algorithm employs cumulative density function analysis to accurately detect hot-spots (CDF). Despite having a maximum detection accuracy of 80.5%, this algorithm is only applicable if PV modules has large data set of hot-spots are available.

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Another promising solution for detecting hotspots without thermal imaging cameras is a photovoltaic hot-spots fault detection method based on a fuzzy-inference system developed by [9]. A Mamdani-type fuzzy controller is used in this method, which has three parameters: output current, voltage and power. The highest level of detection accuracy was 96.9%. The main disadvantage of the fuzzy controller is that training and validation require a large amount of PV hot-spot data. Furthermore, the type of hotspots can be determined with accuracy. However, it is difficult to distinguish between PV modules affect by less number of hotspots and this method is not suitable for detecting PV hotspots early on. In comparison, [10] describes a deep learning-based process for detecting hotspots and microcracks in PV modules. This method pre-processes the input image using electroluminescence (EL) imaging cameras before feeding them into a deep learning algorithm. The Outdoor EL imaging systems require adequate outdoor space and are expensive. This method is not always the case in most roof-top residential PV installations and making this tool difficult to use in practice.

The method of breaking images into small sections that can then be used as significant substance in searching and computing method is known as image segmentation. Various processing techniques, such as clustering and J-fractal image calculation, are used to create these segments. Bottom-up approaches like JSEG process will classify the pixels of an image. These classes are used to identify image segments after pixels have been labelled with classes. To divide image pixels and to create image segments, the classes are clustered. K-Means clustering is used in the existing JSEG image segmentation technique. However, there is several clustering K-means variability that can be used to improve image segmentation results. K indicates that the clustering algorithm has an issue with over segmentation, which is a major issue in the JSEG segmentation process. For image segmentation, we will experiment with available clustering techniques. Many segmentation techniques, such as colour space direct clustering methods, perform well in homogeneous colour regions with texture and color abound in natural scenes. Parameter estimation is a challenging problem that necessitates a large homogeneous region for accurate estimation. In order to achieve this goal, a new method known as JSEG has been proposed. This method eliminates the need to create a copy for each region with its texture. It investigates the homogeneity of colour patterns, which is a method that is more computationally feasible. Enhanced classification and modified K means clustering can be added to the JSEG algorithm to improve it.

In this paper, an updated JSEG method and artificial neural networks are used to segment PV panel images. The nature of non linear vectors necessitates the use of an artificial neural network based classification method related with pattern identification. A multi layer perceptron can be implemented using a back propagation algorithm which is an appropriate default ANN topology for complex patterns.

2. Proposed Method

2.1 Data Collection

The photovoltaic panel image is captured from IR camera Infrasight IS640 during sunny days on 28th July, 2021 between 12:45 to 13:15 in order to prevent shadows on PV modules. This study used an image processing method to recognize hot spots in pv panels in the initial experiment, which used a single cropped image.

2.2 The proposed system

The proposed system was designed to transform image data, segment it, extract features, and classify it. It is an effectual way for locating hot-spots on a pv panel. It works by isolating hotspots from the rest of the environment. Furthermore, the system can generate a report on the state of the PV. The state of thermal data is critical for generating accurate and trustworthy evidence. The proposed method for image processing consisted of three main steps. Preprocessing, segmentation, and feature extraction and identification were the three steps. The following are the steps that were described in Fig. 1:

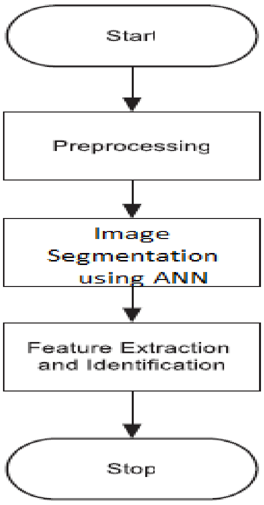

Fig. 1. The Flow chart of proposed system

1) Pre-processing

The features of an image are enhanced by the method called pre-processing. It has the potential to benefit people and solve problems by improving local and global feature detection. In this work, pre-processing begins by converting the RGB image to grayscale, as shown in Fig.2. Color images, while containing additional information than black and white images and it consume extra memory and include unnecessary complications. Grayscale offers a good balance of object vision, compact image and storage space [11]. This arrangement is a monochrome representation encoded as a pixels in two-dimensional array, "white" equaling pixel value 255, with "black" equaling pixel value 0 and various grey tones equaling transitional values between 0 and 255.

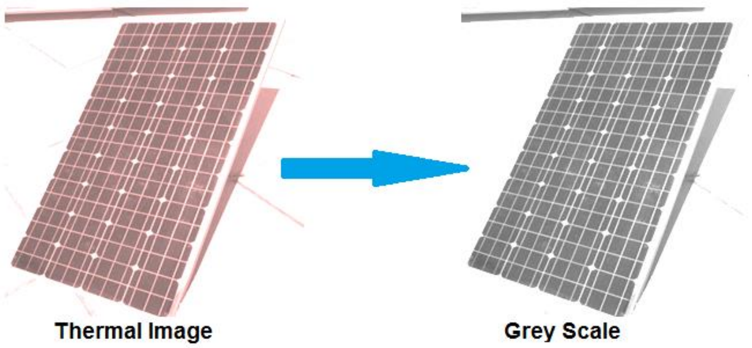

Fig. 2 Image Preprocessing

2) Image segmentation using ANN

The following is a summary of the methodology used in this approach:

A system that mimics the functions of the biological nervous system is known as an artificial neural network. It's similar to how our own brains work. These systems are inspired by the way humans think and are based on the information dispensation model. Artificial neurons [12], also known as neurons, are the fundamental processing elements of neural networks. Neuronal characteristics are similar to the characteristics of biological neural networks under certain aspects. In this system, the configuration is keep on changing in response to external or internal data that flows through it from beginning to end. In a genetic or biological system, learning entails changes in synaptic relationships between neurons. This is also the case with ANN. They are widely used modeling tools, particularly when the original image relationship is unspecified. ANN is capable of learning from examples. After being trained, the result of fully independent data input can be identified using this method.

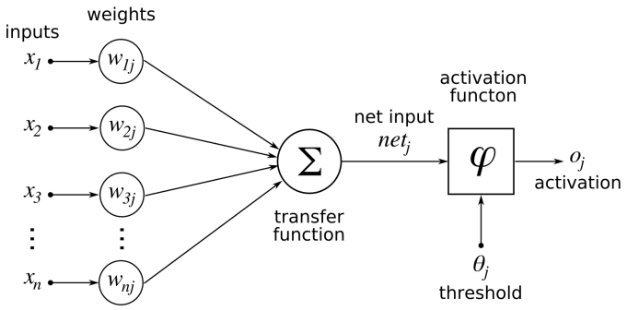

Fig. 3: ANN architecture

The system has N inputs and associated weights up to W_N, as shown in fig. 3. The effects of synapses are represented in a simple mathematical model of a neuron by connection weights that modulate the effect of associated input signals. The transfer function represents the nonlinear characteristics exhibited by neurons. The weights have a direct relationship with the system's learning capability.

A. JSEG

J value segmentation is abbreviated as JSEG. It is a very powerful method for testing image homogeneity with a given colour consistency pattern that is also quite computationally efficient. Image segmentation is one of the most important computer vision applications. The method of breaking images into small sections is referred to as "segmentation". The process of segmenting an image is to observe it and divide it into different segments based on its characteristics like colour, texture, etc. Image segmentation is a technique for simplifying image representation into something more significant and easier to examine. The JSEG algorithm is to generate class clusters by segmenting colour images with homogeneous regions. JSEG makes use of learning techniques in unsupervised condition. It addresses the image acquisition assumptions are: • Image with colour surface regions that are all the same. • Quantized colours are used to represent colour information. • Color can be distinguished between adjacent and boundary regions.• JSEG is a bottom-up approach that uses spatial segmentation. JSEG is a well-known classification method. The concept of region growth underpins JSEG. JSEG is a reliable technique for segmenting natural images. The JSEG algorithm reduces the complexity of colour and texture in images. The JSEG algorithm, in a nutshell, correctly segments images of natural scenes. Natural scene image segmentation is a difficult and time-consuming task because, in contrast to artificial and synthetic images, natural scene images are mostly made up of pure textures with poorly defined texture properties. There is no need to make individual adjustments to the parameters for each image. On a quantized class map, JSEG applies a spatial segmentation algorithm. The J image represents the region at interiors and their boundaries and it is considered using a homogeneity evaluation J in spatial segmentation. The image is then segmented using a random class region merging algorithm. It gives you the ability to estimate and evaluate colour textures.

The JSEG scheme divides the segmentation process into two stages, as shown in fig. 4, colour quantization and spatial segmentation.

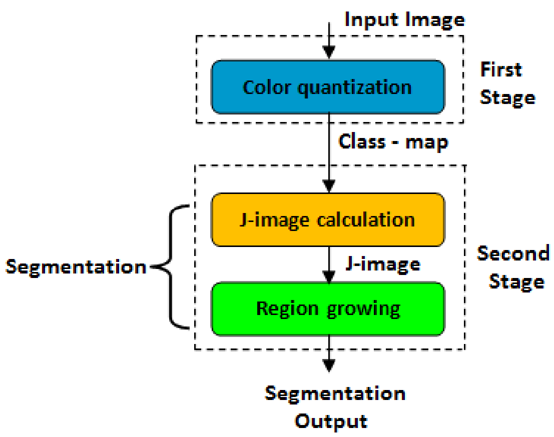

Fig. 4 JSEG segmentation process

The first step is to categorize images with dissimilar colors into classes that might be used to distinguish different regions within an image. The class map image is created by replacing pixels with corresponding and equivalent colour class labels. The focus is on spatial segmentation, with the class map as a proposed principle for "good" segmentation. The proposed principle for excellent class map segmentation focuses on spatial segmentation. The region growing method, which is based on multi-scale J images, is used to segment the image. The similarity of the pixels in the region determines them. When a region expands, it receives a large number of segmentation maps with a large number of segments. The region-growing method's scales are important factors in determining the accuracy of the segmentation process.

3) Feature Extraction and recognition

Feature extraction is used to obtain information about the regions in the segmented image after the segmentation process. The colour feature must be extracted from the segmentation result, so feature extraction is required. The hotspot region is white with a pixel value of one, while the background image has a pixel value of zero. In order to complete the identification process, these values were extracted.

2.3 Methodology used

The following is a summary of the methodology used in this approach:

Step 1: Open the image: The image is directly uploaded into the system. When load database button is pressed, the system will check the number of images to be loaded into the system and then segmentation process will start. We use the image of PV panel affected by hot-spot in this method. As shown in fig. 5, this image is directly loaded into the system.

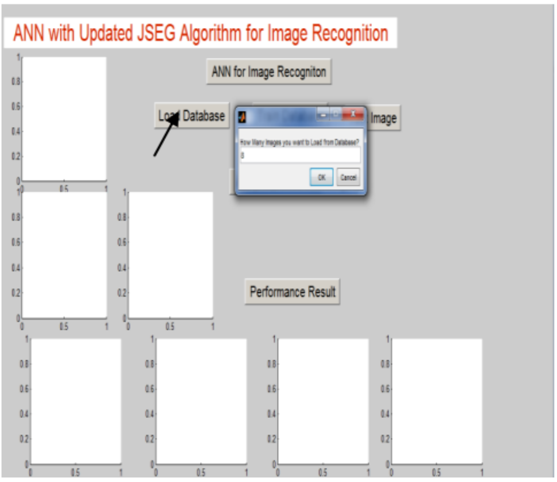

Fig.5 Database loading

Step 2: Train the database: The neural network is trained in this step. The neural network training begins when we click on train database in Fig. 5. The system requires 120 iterations to be successfully trained, as shown in Fig. 6. The system is now ready to be trained once it has been initialized. When training a neural network, several factors are taken into account, including the number of iterations required, the time required to instruct the system, presentation, gradient, and checks for confirmation. The values of these parameters may differ between images. The presentation and gradient values for this image are 0.09 and 0.05, respectively. Gradient error is the type of error that is generated here. The term "gradient" refers to the change in error energy as a function of weight value. To train a neural network, find the smallest value of a complex nonlinear function known as the error function. We set our system to 4000 iterations, but the system, also known as epos, trains in 126 iterations and also specify the number of images to train. As shown in fig.6, we have chosen the PV panel image. In a neural network, training is a critical step. Because of this feature, the neural network's functionality is said to be similar to that of the human brain.

Step 3: Image Testing: The image was tested in this step. The image that was loaded into the database was compared to the image that would be trained. The test image matched the image loaded from the database in the system, as shown in fig. 7. The segmentation process can now begin with the matched image.

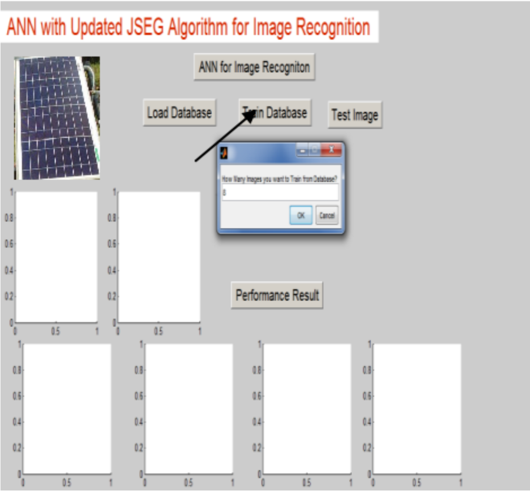

Fig. 6 Database training

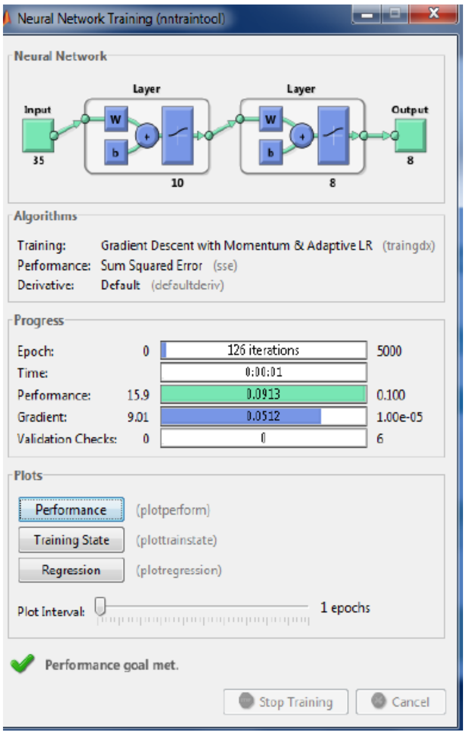

Fig. 7 Training of neural network

Step 4: Use the JSEG algorithm that has been improved: There are several windows in the JSEG method. Here, 9*9 windows are used. The number of pixels in the image has an inverse relationship with the window size. The performance of the segmentation results is affected by the window size. These windows, centered over pixels, are used to calculate J values. The sizes of image regions, as well as the intensity and colour boundaries in images, are determined by window dimensions. Region borders are detected by the larger window size, while intensity changes are detected by the smaller window size. Multistage J images can be calculated and segmentation on different images performed by varying the window size.

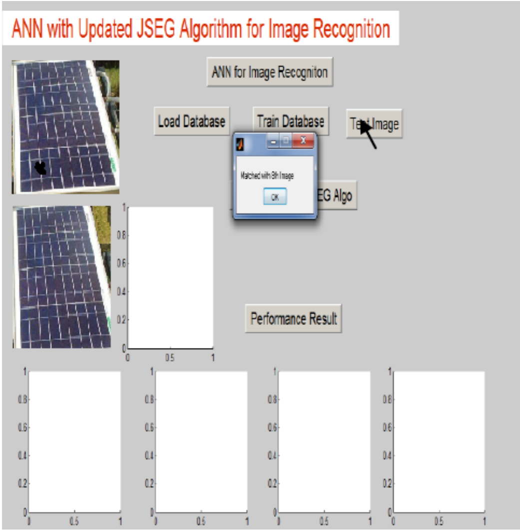

Fig. 8 Testing of image from database

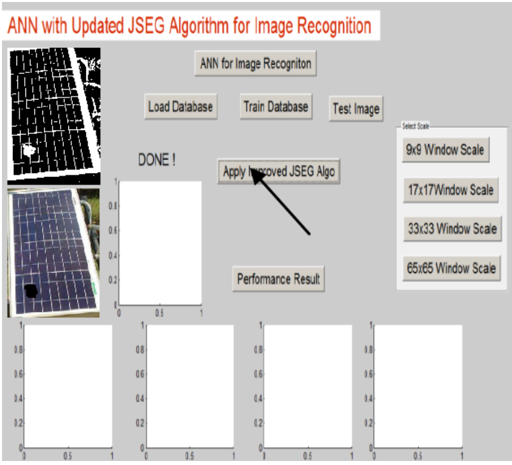

Fig. 9 Improved JSEG for segmentation

Step 5: Display results of final Segmentation: Using the improved JSEG method, the segmentation results for four windows were displayed in this step. With the help of the final segmentation results, we can easily compare different segmentation windows.

Step 6: Performance Parameters: This step compares various types of performance parameters. Computational time, performance, training state, and regression are all variables to consider. The performance of these parameters is related to the segmentation results.

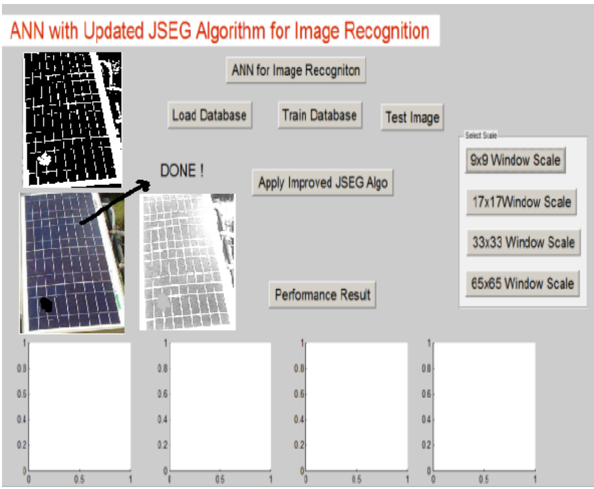

Fig. 10 9*9 windows with improved JSEG for segmentation

After segmentation, feature extraction is used to obtain details about the segmented image regions. The colour characteristic must be extracted from the segmentation result, so feature extraction is required. The segmented image has a pixel value of 1 for the hotspot region and 0 for the background image. In order to complete the identification process, these values were extracted. Figure 11 depicts the outcome of the Feature Extraction and recognition process.

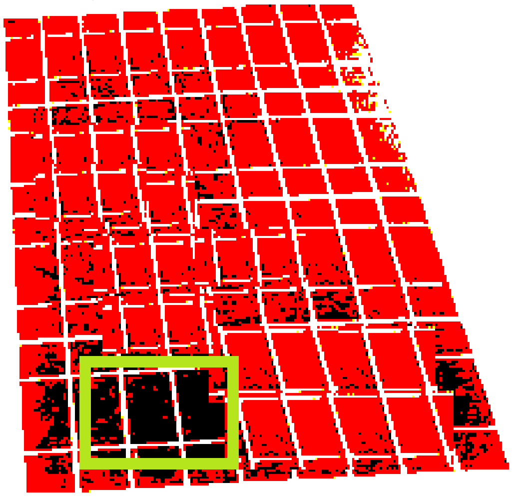

Fig. 11. Output result through feature extraction

Figure 11 shows the hot-spot area of the PV module with a bounding box around it. The bounding box could be a rectangular box defined by the coordinates of x and y axis in the upper left corner of the rectangle. When identifying the objects, bounding boxes are commonly used to show the target location. The hot-spot area is the focus of this study, and it is identified using pixel values. If the pixel value of the region is 1, then the bounding box is drawn around it.

3. Results and Discussion

To perform image segmentation and evaluation, the proposed method made use of a MATLAB computational environment. The accuracy was computed during the evaluation process, as stated in (1).

$$Accuracy = \frac{TP+TN}{TP+TN+FP} \tag{1}$$

In this study, the term "accuracy" refers to how well the segmentation process separates the foreground and background (hot-spot). It is a subset of the total number of pixels that are true segmented [13]. In this assessment, understanding the terms False Positive (FP), False Negative (FN), True Positive (TP) and True Negative (TN), is critical. The evaluation matrix for these variables is shown in Table 1. The table represents the output of the proposed system corresponding to its reference image. It is a appropriate method for determining the image segmentation accuracy.

TABLE I Evaluation Matrix

System Results	**Reference Image**	
	Hot-Spot	**Background**
Hot-spot	TP	FP
Background	FN	TN

- False Positive (FP) is the Background that pixel segmented as hot-spot in system
- False Negative (FN) is Hot-spot pixel that segmented as background in system
- True Positive (TP) is the Hot-spot pixel that segmented as hot-spot in system.
- True Negative (TN) is Background pixel that segmented as background system.

By comparing the manually segmented reference image to the ANN segmented image obtained, the original image is evaluated. This method of evaluation is known as supervised evaluation. High evaluation accuracy is achieved by being able to observe the pixel of the ANN segmented image and the pixel of the reference image in real time [14]. The image accuracy achieved in the experiment was 99.5%.

4. Conclusion

The aim of this study is to find a hot-spot area on a photovoltaic module. This research presents an ANN-based segmentation method for segmenting grayscale thermal images, as well as preliminary results from an ongoing study. It is critical in determining the information of thermal image features during pre-identification. Cropped photovoltaic thermal images were used to test the proposed method. According to the experimental results, the proposed method achieves a high level of accuracy of 99.5%. It demonstrates that the hot-spot has been segmented successfully.

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