Design of Real-Time Monitoring of PV Panels and Grid Connection Systems

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ABSTRACT - The integration of embedded systems in solar measurement systems allows the remote monitoring of small stand-alone photovoltaic (PV) systems, enhancing the performance and the maintenance of the smart home control system. In this project, we present a multifunctional, low-cost, and flexible system for PV panel environmental monitoring and calculate the energy from the panel and energy utilization. .This system employs an embedded based on a microcontroller with IoT connectivity that allows remote device monitoring. The proposed system can be monitored via the web/PC based application.

INDEX TERMS Photovoltaics, solar energy, thermal images, inter section over union, segmentation.

I. INTRODUCTION

Solar energy is the most affordable and fastest growing source of renewable energy. In an hour, the sun gives off more energy than the world consumes in one year. The most widely used solar technologies for businesses and homes are solar photo-voltaics for electricity and solar water heating. A collection of PV modules is called a PV panel, and a system of PV panels is called an array. Arrays of a photovoltaic system supply solar electricity to electrical equipment. Solar panels are designed to give the maximum output when exposed to solar radiation. The working conditions of solar panels can be affected by atmospheric conditions like dirt, dust, the presence of foreign objects, shadowing, or functional conditions like cell mismatch or damage, string mismatch, winter shading, soiling, rooftop conditions, etc., which result in the generation of hotspots. Installation of panels at a height on the rooftop of buildings or over a larger area, makes the inspection process of individual PV panels significantly time consuming, complicated, and expensive. Fault detection and analysis are two of the most important parts of the operations and maintenance section.

Thermal imaging is a non-invasive and non-destructive method used for inspection of solar panels under load, so shutdown isn't required. Appropriate use of thermal imag-ing cameras shows accurate temperature differences between cells, which allows us to identify faults at an early stage. Thermal cameras capture raw thermal images, which con-tain important information used for image analysis. With thermal image analysis, problematic areas can be identified and repaired. Fault detection and classification are necessary for the efficiency, reliability, and safety of PV systems.

One of the ways to improve PV array output is to ensure that the array operates in optimal output conditions at all times. Once installed, PV arrays are expected to operate with least human intervention. PV arrays perform below optimum out-put power levels due to faults in modules, wiring, inverter, and so forth [1]. Most of these faults remain undetected for a long period of time resulting in loss of power. Experts assigned to locate and fix the faults within an array need to take time consuming field measurements. Fault analysis in the solar PV arrays is a fundamental task to eliminate any kind of dangerous and undesirable situations arising in the operation of PV array due to the presence of faults [1], [2]. They must be detected and cleared off rapidly. Without proper fault detection, noncleared faults in PV arrays not only cause power losses but also might lead to safety issues and fire hazards [2], [3]

The primary objective of this proposed work is to study and investigate the effect of pre-processing technique on the accu-racy of fault detection in solar panels. Image pre-processing involves removal of noise using selected filters and image enhancement. Faults are detected and located by applying two segmentation techniques on pre-processed images. Fil-tering and image enhancement using histogram equalization are applied on original thermal images.

Various filters such as Mean, Median, Bilateral, and Gaussian are tested. Fil-tered images are enhanced using histogram equalization. Two segmentation techniques with histogram-based color thresholding and separate color channel-based thresholding are applied on pre-processed images. This paper contributes to detection of hotspots in thermal images of solar panels.

II. RELATED WORK

Bharath Kurukuru et al. [4] have used Canny edge detection and Hough Transform technique for segmentation of faulty panel from a series of panels. From faulty panel, the fea-tures were extracted, and classification was

done. Authors in [5] have used color thresholding in HSV space for RoI extraction. This segmented image was applied to Canny edge detection. Contours detected under certain thresholds are
filtered resulting in a binary image having borders of PV modules. Dotenco et al. [6] modelled foreground in photo-voltaic modules using a Gaussian distribution. To separate foreground from background, threshold was calculated from normalized temperature map. But due to high variance of background regions, it cannot be completely excluded from the foreground. Hence, the variance Tvar of the normalized temperature map Tnorm using a 3×3 kernel was used, which allowed region detection with high inconsistency and were probable to be part of the background. K-means algorithm was used to cluster the thermal image into many regions and identify the damaged area [7]. Additionally, to select the optimal number of clusters Elbow and gap methods were used with various values for Guerriero and Daliento [8] proposed segmentation method based on gradient analysis and edge detection. Edge detection method automatically selects the area in the thermal image related to the specific PV panel to be analyzed. Aghaei et al. [9] proposed the segmentation method to identify faulty panel using luminance of gray scale image of solar panel. Image is separated into black and white areas using threshold based on luminance and standard deviation of image.
In the segmentation algorithm used by Kim et al. [10], panel boundaries were extracted with horizontal filtering, vertical filtering, and a modified tiered histogram clustering method. By applying an additional mor-phological algorithm, initial panel boundaries were obtained. With the geometry of surrounding panels, these extracted panel boundaries were refined by processing digital image in HSV color space. Kaplani [11] presented a method which automatically detects EVA discoloration in PV cells. Primar-ily based on hue, segmentation is applied in HSV color space. Regions with undefined hue are masked with saturation com-ponent. Next, with different tones of color in regions to detect different strengths of browning effect, value component is used. Authors [12] have extracted temperature information from thermal image such as average temperature, maximum temperature, and minimum temperature. Based on these val-ues, threshold was selected. Count value was increased if the temperature value was less than high and low threshold.
This method determines a hot pixel (seed pixel) in the input image for segmentation. After pre-processing the image, the value of the hottest pixel is determined by finding the highest pixel value. After this, all the neighboring pixels were checked if they are related to the hot pixel, called as seed pixels *SP*, or background pixels *BP*. Winston et al. [17] have used Feed Forward Back Propagation Neural Network technique and Support Vector Machine (SVM) technique to classify solar panel faults as micro-cracks and hotspots. Six input parameters like percentage of power loss (PPL), Irradiance (IRR), Open-circuit voltage (VOC), Short circuit current (ISC), Panel temperature and Internal impedance (Z) are used as input to these two classifiers.

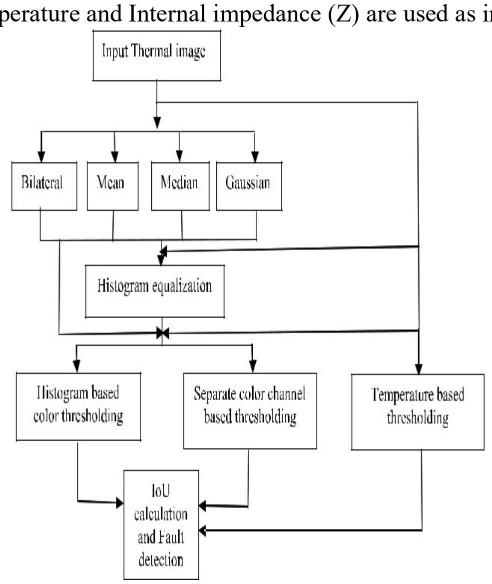

FIGURE 1. Proposed methodology.

III. METHODOLOGY

A. DATASET

FLIR C2 thermal camera is used to capture thermal images from various solar plants across India. These images are captured at different times and dates. The images are provided by PV Diagnostics, Mumbai, India.Total number of images belonging to five different classes are shown in Table 1. Fig.2 shows sample images labelled by experts into five different classes as single cell hotspot, mul-ticell hotspot, potentially induced degradation (PID) fault, diode fault and dust/shadow hotspot.

B. PRE-PROCESSING TECHNIQUES

The objective of pre-processing is to improve image data by suppressing unwilling distortions or to enhance some image features important for further processing. Four basic filters and histogram equalization technique used in this approach are detailed as below:

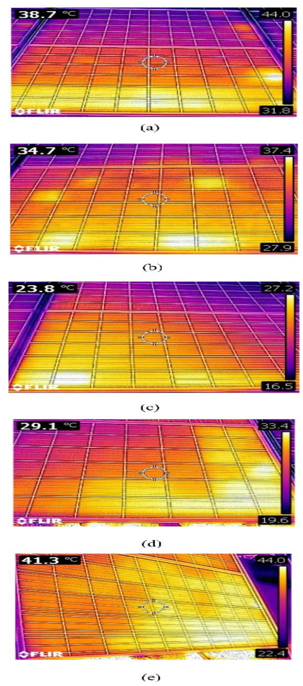

FIGURE 2. Various faults on solar panel (a)-diode fault, (b) Multicell hotspot, (c) Single cell hotspot, (d) PID fault, (e) Dust/Shadow Hotspot.

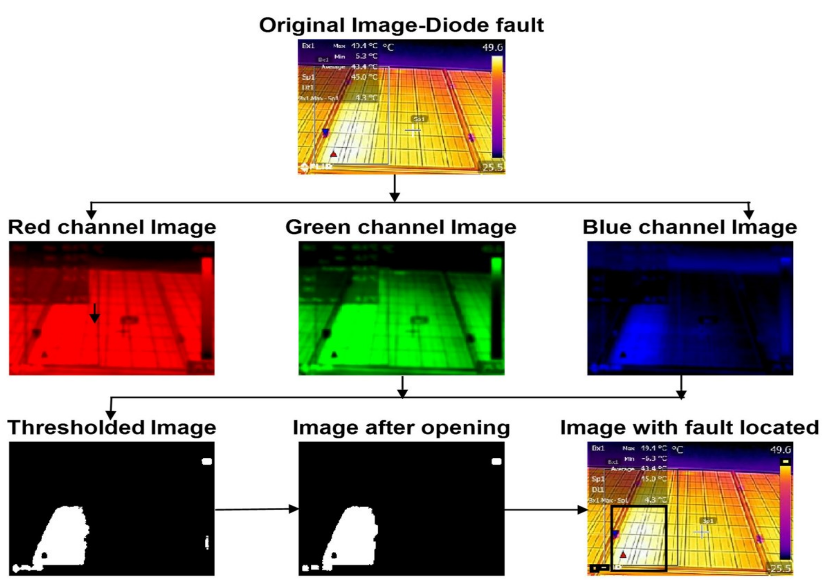

FIGURE 8. Output of various stages as original image (Diode fault), RGB channel images, thresholded image, image after opening and image with fault located for segmentation based on color channel.

IV. RESULTS AND DISCUSSION

To assess the effect of pre-processing on accuracy of fault detection and demarcation, Intersection over Union (IoU) for

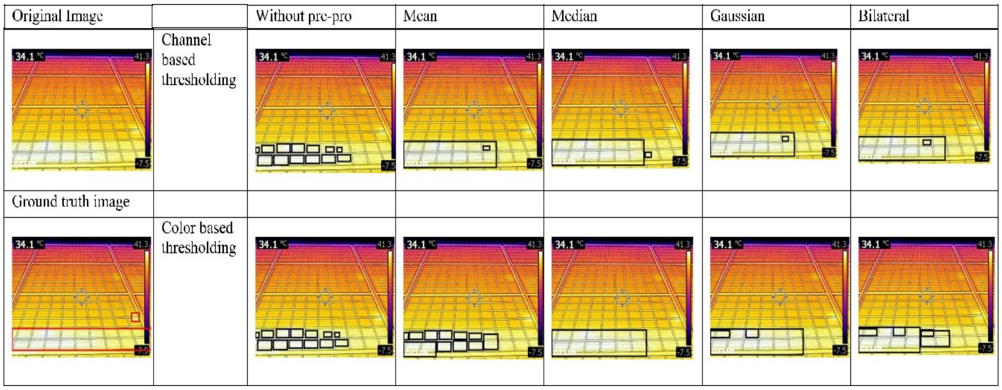

FIGURE 11. Qualitative analysis for fault detection without pre- processing and with 4 filters using channel and color-based thresholding.

TABLE 4. Segmentation results with histogram based color thresholding on filtered images.

	Bilateral filter	**Mean filter**	**Median filter**	**Gaussian filter**
Fault	**Mean IoU**			
Diode	0.199383	0.189443	**0.249386**	0.210068
Dust	0.091041	0.083581	**0.08639**	0.099608
Multicell	0.197865	0.184977	**0.238425**	0.19906
Single	0.446065	0.443581	**0.457015**	0.445686
PID	0.275508	0.270795	**0.298605**	0.278559

TABLE 3. Segmentation results based on separate color channels on filtered images.

	Bilateral filter	**Mean filter**	**Median filter**	**Gaussian filter**
Fault	**Mean IoU**			
Diode	0.144148	0.151845	**0.215801**	0.154348
Dust	0.117275	0.142022	**0.161894**	0.142086
Multicell	0.205341	0.213927	**0.266428**	0.212648
Single	0.439561	0.44232	**0.445705**	0.435979
PID	0.242625	0.250927	**0.280037**	0.249695

V. CONCLUSION

The machine learning based solution for monitoring hot spots of PV panels using temperature sensors has been proposed. A working prototype of the system was tested successfully under harsh conditions. An email protocol has been used to send email alerts of hot spots remotely. Research is further to enhance the range and test the solution using multiple PV panels

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