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Solar Cell Panel Crack Detection using Bacterial foraging Optimization Algorithm

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***Abstract*— A solar cell panel as an efficient power source for the production of electrical energy has long been considered. Any defect on the solar cell panel's surface will be lead to reduced production of power and loss in the yield. In this case, inspection of the solar cell panel is essential to be performed to obtain a product of high quality. Some inspection methods have been developed, but in any event non-contact, non-destructive and efficient testing methods are necessary. This paper proposes an automated inspection system based on an image-processing approach for solar cell panel application in order to detect any cracks which may be appeared on the surface of solar cell panel. The Bacterial foraging (BF) algorithm as a main constituent of our proposed method is used for edge detection in the solar cell panel. Subsequently, some features like cracks and bus bars will be extracted and we will classify defected products and cracks based on the positions of the bus bars using Fuzzy logic. In this proposed method, an automated inspection system of solar cell panel proposed which has potential to get good results based on Bacterial foraging optimization algorithm.**

***Keywords*— Solar cell panel, automated inspection system, BF-based edge detection, crack detection.**

I. INTRODUCTION

Electrical energy generation has been a critical issue in aircraft and orbital equipment such as satellites [1]. Since energy production is expensive [2], using renewable energy sources such as wind, solar as a suitable solution has been widely used to generate electrical power [3]. Recently, solar energy and photovoltaic (PV) have been significantly considered as an important electrical energy generation resource . It can be obtained by converting solar energy to electrical power with highest efficiency and high reliability. Different kind of solar cell products have been developed which crystalline silicon as the most common kind of mono-crystalline varieties are produced whereby poly-crystalline solar cells are more applied to produce solar cell panels and are more popular than mono-crystalline ones. Whether the solar cells are based on single crystalline or polycrystalline types of silicon, the most important factor is avoidance of any cracks and defects to obtain a product with high quality.

The most common fault in solar cell panels are concerned with cracks which are found on the surface of solar cells and these can lead to loss of yield. In this case, during the assembly and production processes, it is necessary to ensure the obtaining of a good end-product. Sometimes mechanical cracks such as micro cracks will occur on cell panels in any event. They can directly influence efficiency and then reduce performance [6]. It is necessary to detect cracks on solar cell panels and consequently reject imperfect products. Lot methods have been developed to inspect the solar cell panels, and these have different weaknesses and strengths. Some inspection systems are acoustic microscopy and impact testing , Radiometric pulse and thermal imaging [9], hyper-spectral imaging [1], defect surface luminescence [10], resonance ultrasound vibration and image processing approach to inspect the solar cell which were all presented for crack detection in solar cell panels. Still it is essential to find an efficient approach, which will be a non-contact, non-destructive and low-cost inspection system. We will discuss about some methods in the literature review section. In this paper, a fully automatic, non-contact, and non-destructive system is proposed in order to inspect solar cell panel surfaces, based on an image processing approach which is implemented real time. The Bacterial foraging Optimization (BF) algorithm as a main component of our proposed method is chosen to detect the edges of the captured image. Detected edges should be extracted so that some features such as cracks and bus bars will be recognized. In the continuous Fuzzy Logic classification method, it is used to classify cracks based on location of bus bars which are positioned on solar cell panels. We will implement our proposed method by MATLAB to write the code. We expect to achieve an automated inspection system of solar cell panel with high reliability and higher accuracy by our method.

II. LITERATURE REVIEW

In this section, we will discuss previously developed inspection systems and testing methods. Currently, there are many different methods. In order to facilitate easy discussion we categorize them into two groups here. The first category is the image processing approach, and the other one is on non-image processing techniques.

Reference [13] implemented an inspection system based on image processing approach. They focused on crack detection on the edge and inside the captured image of solar cell panel. They detected and classified the cracks based on the gray value difference of the pixels between a region and its surrounding pixels. Their developed system consisted of image converting, adjusting of image, Gauss-Laplacian image transformation, merging of distributed points to obtain an integrated region, contour recognition to detect the cracks which are located on inside or edge of a solar cell.

Reference [1] presented a system based on the image processing approach for defect detection in solar modules. They used semiconductor electro-luminescence devices for capture from solar cell modules. They presented different types of defects and classified them into black pieces, broken grid, fragmentation, and cracks in the solar cell module. Their system software was composed of gray scale transformation, binary and feature extraction. They proposed the binary method based on transformation of a feature’s gray value between different regions. Their identification method to distinguish the crack from a broken grid is based on tracking the trajectory; a crack is detected in terms of the projection ratio of furthest and nearest points in horizontal degree in each solar cell. Their results for recognition rate of defects were presented as the following: black piece is 99%, broken grid and fragmentation is 95% and the rate for crack detection 80%. Reference [14] developed an inspection system based on machine vision for indentifying micro cracks on solar cell wafers. Their system has a quick computational operation of 0.09 s for a 640 * 480 image. Reference [15] proposes a system based on machine vision to detect invisible micro cracks in solar cells. To seek these out, they set up an IR imaging system to capture images of interior micro cracks. They applied flaw detection algorithms to extract micro crack features of solar cells. Their experimental result illustrated in 99.85% accuracy of their flaw detection system.

Reference presented an emitting light material to detect defects on solar cells based on the existing difference in intensity distribution of electro-luminescence (EL). Reference developed an infrared thermography method for defect detection in solar cell panels. Their system consisted of an IR camera in order to capture the image of the solar cell, propagating thermals along the surface of the solar cell and edge detection operator to detect the edge of cracks. On the other hand, some non-image processing testing methods are presented by [1] who developed an inspection method based on hyper-spectral imaging to detect cracks in solar cell panels. For laser scanning and hyper-spectral imaging, the spectral angle mapper was adopted to recognize the defects on solar cell panels. Reference [7] developed a system using acoustic measurements. It can be accurate by excitation of vibratory modes in a solar cell which can detect cracks and their locations.

III. RESEARCH METHODOLOGY

This section expresses the architecture of our proposed hardware and software systems.

A. Hardware Framework

The hardware architecture of our system is depicted in Fig. 1. It illustrates an automatic inspection system of solar cell panel which consists of three parts. The first part refers to capture the image of solar cell panel. It consists of an infrared CCD camera and some lamps behind the solar cell panel. The second

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part includes an image analysis machine which will analyse the captured image from the prior part. The last one is a PLC controller part that gets the signal from the computer and selects the rejection line or pass to next step for further processes. If any crack is found from image analysis machine, it sends a signal to PLC and it chooses the rejection line to discard.

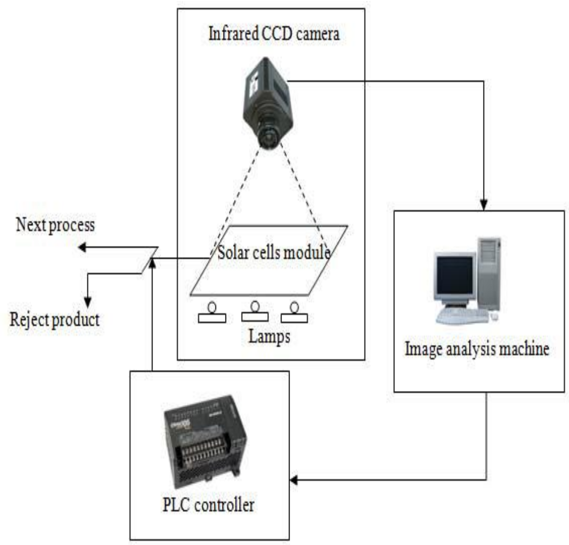

Fig. 1 Hardware framework

B. Software Framework

In this section the structure of our software components will be considered. As previous mentioned, we will develop our proposed method by MATLAB to write the code. Fig. 2 illustrates the steps of our software component. Also the data flow diagram is depicted in Fig. 3.

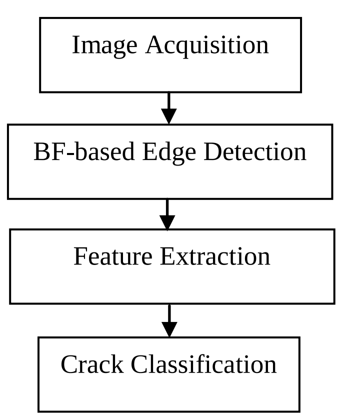

Fig. 2 Steps of software component

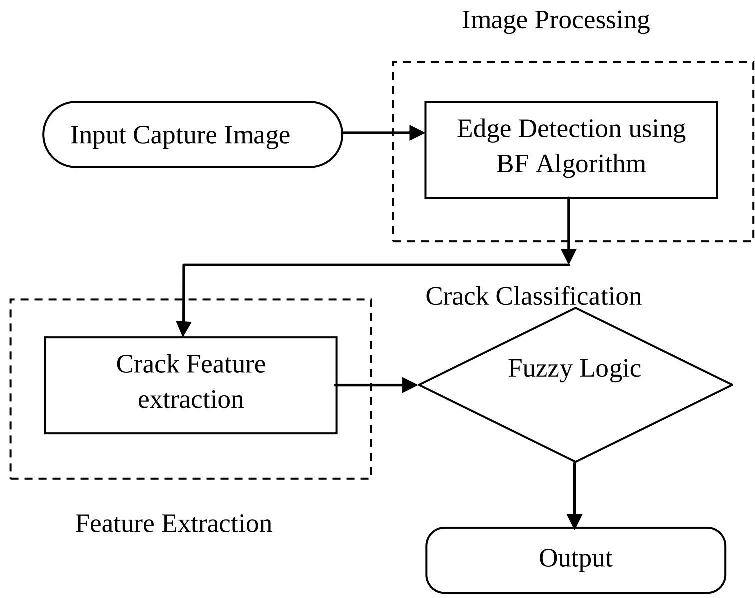

Fig. 3 Data flow diagram of software environment

1) Input of Captured Image: Using the camera we capture the image as a gray scale format, the originally captured image being shown in Fig. 4[19].

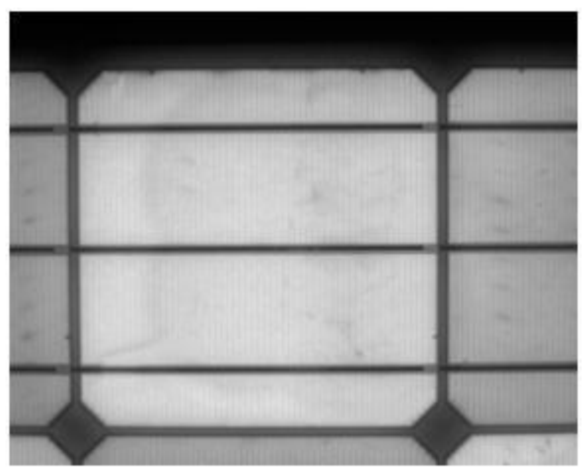

Fig. 4 Captured image from camera

2) BF-Based Edge Detection:

The foraging process of a bacterium, Escherichia coli, living in the intestine, is modeled through four steps of chemotactic, swarming, reproduction, and elimination and dispersal. It focuses on the number of pixels which are on a curve, because the best edges exist on curves. It applies for any pixel of an image in order to find the best curve which often happens on the edges. In this case, optimizing of edge detection will be performed on pixels from the captured image according to the path of the connected curves on the image. So, the edges of regions will be detected. In this method, two important parameters were considered, i.e. homogeneity and uniformity from curves. They were applied to make the objective function for BF edge detection. This method can also be used in noisy images and there is no need to apply any filter. The mechanism of the edge detection operator was based on encoding the characteristic of the image to an integer value between 0 and 8. These values encoded as a particle are based on the direction of the movement on a curve. As a result any particle was denoted as k1, k2, k3… kn. where ki is an integer value between 0 and 8 . Homogeneity is similarity of homogeneity pixels on a curve and uniformity is the similarity of intensity of pixels along the curve. In this method, measuring homogeneity for Homogeneity and measuring similarity of intensities for Uniformity of pixels will be considered. It includes the average of homogenous pixels based on equation (4).

Furthermore, the objective function is calculated as the main element in BF optimization. That is based on motioned parameters (homogeneity and uniformity). The objective function is used to find a large region of homogeneity and small region of uniformity.

3) Feature Extraction: According to detected edges from the previous step of our proposed system, we need to recognize different regions on the captured image such as cracks and bus bars. In this case, the captured image is separated to connected and disconnected regions by grouping neighboring pixels of similar features and different gray value of pixel. By this way, we can obtain desired information such as cracks which they have dark gray pixels. By counting the dark gray pixels, we can extract the bus bars and crack s as well.

4) Crack Classification: The main characteristic of cracks is the difference in value of gray and dark gray. As already discussed, the cracks will be detected by BF-base edge detection operator and crack extraction from previous steps. In this step we consider two separate operations for classification phase. First one is crack classification and the other one is defected and undetected product classification. We discuss about our strategy to classify the cracks. The main factor to categorize cracks in our proposed method is based on location of bus bars. As Fig. 6 illustrates, bus bars are thick lines on the solar cell. As prior discussed, we can detect them easily based on edge detection and feature extraction phase. After that, bus bars coordinate will be detected by counting the pixel based on 2-dimensianal coordinate (X,Y). In addition, position of crack will be detected based on bus bars coordinate. Totally, for position detection and crack classification a clause structure is necessary. We use a simple Fuzzy inference system to classify perfect and imperfect solar cell panels. It is used to classify the cracks based location of bus-bars as well. Fuzzy Logic is selected because it is able to mimic human reasoning and easy to implement.

A membership function is defined as fuzzy sets to declare some variables for a range of possible values. The variables are between, outside and between, and outside. Fuzzy rules will be considered by .

• If the crack is between the bus bars then probability is between Fig. 7.

• If the crack is outside and between the bus bars then probability is outside and between Fig. 8.

• If the crack is outside of the bus bar then probability is outside Fig. 9.

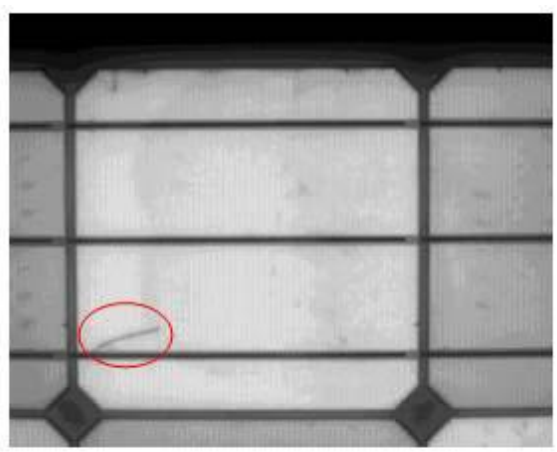

Fig. 7 Mono-crystalline solar cell with micro-crack between the bus bars

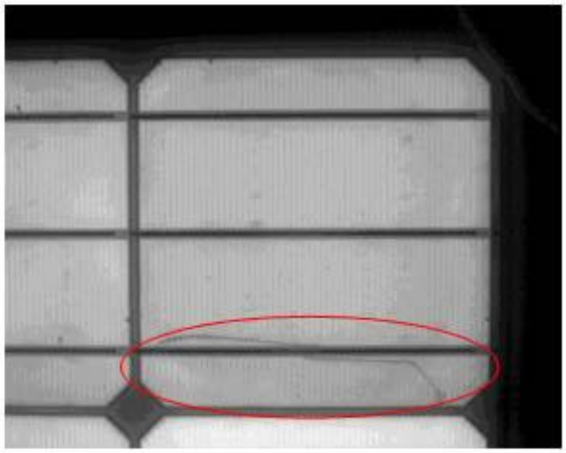

Fig. 8 Mono-crystalline solar cell with micro- crack outside and between the bus bars

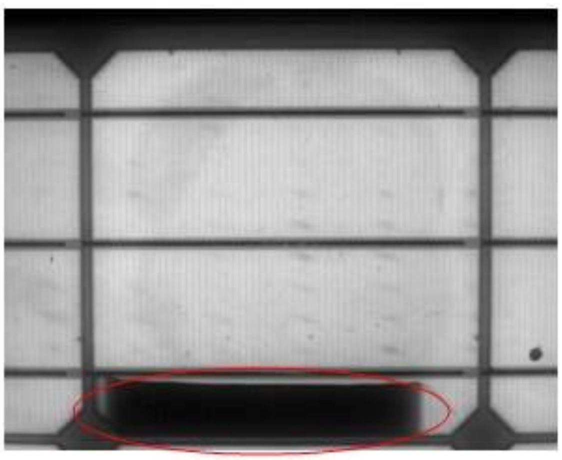

Fig. 9 Monocrystalline solar cell with a crack outside of the bus bar

IV. DISCUSSION

In this research, we proposed an automated inspection system of solar cell panels based on Bacterial foraging Optimization (BF) algorithm. As mentioned above, the proposed system has separate hardware and software parts. The main part of our proposed system focuses on detection of crack detection using by BF. In this case, BF is chosen to edge detection operation in image processing approach related to software part. This technique can be applied in noisy images and it does not need to use any pre-processing operations such as filtering to remove the noise on the image for simple shape which is obtained good results. We use it for edge detection operation. Then, features like crack and bus bars will be extracted and then defected product and position of crack will be classified.

Fuzzy Logic inference system is chosen for classifying perfect and imperfect solar cell panels and crack position based on detected bus bars. On the other hand, charge coupled device (CCD) camera is used to capture high-quality images and some lamps with high intensity illumination are installed to illuminate the background. In addition, computer machine is equipped by software components such as image processing tools in order to analysis the images. From one side, it connects to CCD camera to get the captured image and the other side connects to a PLC to send the signal for selecting rejection or passing line.

V. CONCLUSIONS

This paper proposes an automated visual inspection system for solar cell panels using Bacterial foraging Optimization (BF) algorithm. As previously BF based algorithm are developed in edge detection [7] and object recognition [11] which they obtained good results. BF-based edge detection as main constituent of our proposed method is used to edge detection in image processing approach. Then some features like cracks and bus bars will be detected and crack will be classified based on bus bars. The classification phase will be accomplished using Fuzzy Logic. Consequently, defective products will be rejected using the PLC controller. As result, an automated inspection system of solar cell panel proposed which has potential to get good results based on provision research on BF algorithm.

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