Determination of Defective Photovoltaic Module by using Thermography

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ABSTRACT: The electricity generating efficiency of photovoltaic (PV) modules can be decreased due to corrosion, dust, short circuit or errors of interconnections. During PV module operation, the temperatures of defective cells are higher than the temperatures of normal cells. And the defective cells appear as hot spots in thermal infrared images. Therefore, thermal infrared images can be used to detect PV module's malfunction. In case of large scale solar power plants, we can enhance the efficiency of the inspection by using drones with on-board thermal infrared cameras. Furthermore, if we add the computer vision technology in this inspection method, we can recognize the defective PV modules automatically. For the realization of the technical fusion, the development of panel area extraction algorithm is necessary. In this research, the panel area extraction algorithm based on Canny edge operator was developed. For development and evaluation of this algorithm, we used a thermal infrared image of PV modules collected from a drone. As a result, we could find that this algorithm can determine the individual panel area although the edge of panel area is not linear. After panel area extraction, we compared intensity histogram of each panel, and then analyzed statistical characteristics of malfunction panel intensity. As a result, we could find that we can detect malfunction panels based on statistical analysis.

1. INTRODUCTION

Currently, solar energy has been quite popular in the world as a kind of eco-friendly energy. However, the PV panels of solar power plants must installed outdoors to collect radiation energy. It means the PV module can be affected by various environmental sources such as wind, salt, snow and dust. Corrosion and short circuit of cells can be incurred by long-term exposure of the nature environment. Then, the electricity generating efficiency of PV modules can be decreased due to corrosion, dust, short circuit and other defective sources. Therefore, regular fault diagnosis and repair is required to maintain the performance of PV systems.

During PV module operation, the temperatures of defective cells are higher than the temperatures of normal cells. And the defective cells appear as hot spots in thermal infrared images. Therefore, thermal infrared images can be used to detect PV module's malfunction. Infrared thermography is one of the widely known techniques for the detection of defective PV modules in the solar power plants. Meanwhile, large-scale solar power plants are increasing these days to conserve fossil fuels. To test large-scale solar power plant with a handheld thermal camera would be a time consuming work.

In case of large scale solar power plants, we can enhance the efficiency of the inspection by using drones with on-board thermal infrared cameras. The technology of unmanned aerial vehicles (UAV) has rapidly improved in the past decade. Multifarious application technologies of UAV have been developed through the fusion of various sensor. Diagnostic methods of PV modules by using thermal imaging camera drones are also being developed as a part of drone applications. Also, researches about field inspection of PV modules using drone-mounted thermography have announced recently (Quarter et al., 2014; Buerhop and Scheuerpflug, 2014; Tsanakas et al., 2015b). However, these technologies require human decision to recognize hot-spots. If we add the computer vision technology in this inspection method, we can recognize the defective PV modules automatically.

For the realization of the technical fusion, the development of panel area extraction algorithm is necessary. If the automatic extraction of each panel area in the thermal image is available, we can recognize malfunction panel by using statistical analysis results of pixel intensity from each panel area. And the statistical analysis of pixel intensity from each panel can be automatized by modelling the intensity profile of normal panel. Canny edge detection (Canny, 1986) is considered as a well-established and reliable tool in various research fields such as computer vision, computer-aided medical diagnostics, infrared thermography and digital radiography (Tsanakas et al., 2015a). Therefore, we developed a panel area extraction algorithm based on Canny edge detection operator. For the development of this algorithm, we selected an aerial thermal infrared image which was taken from Paul Kitawa

Company. After panel area extraction, we compared intensity histogram of each panel, and then analyzed statistical characteristics of malfunction panel intensity.

2. DEVELOPMENT OF PANEL AERA EXTRACTION ALGORITHM

Figure 1 shows sample thermal infrared image of the PV power plant (left). In the panel array, there is a panel that some hotspots exist. Also, there is a panel that the temperature of panel surface is significantly higher than the other panels. Therefore, this sample image will be a good example for analyzing the intensity characteristics of malfunction panels. When we apply Canny edge operator, we might get the edge information like right image of Figure 1. However, there are some noises outside of the panel area. In this research, elimination of background of panel area is not an interest. Therefore, we selected only panel area like Figure 2 (A) to develop our panel area extraction algorithm.

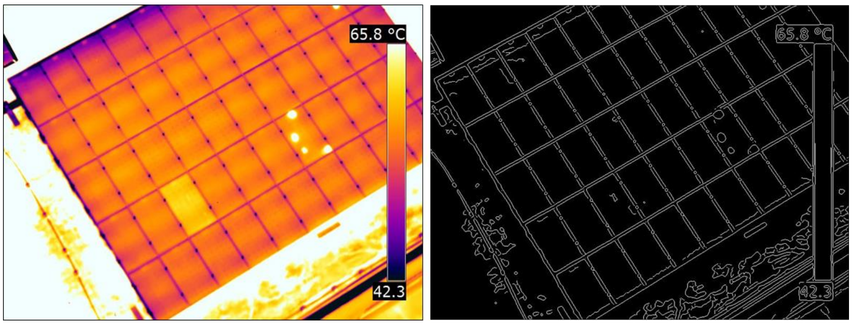

Figure 1. Original thermal infrared image (left) and application result of Canny edge operator (right)

To acquire the input data of Canny edge operator, we converted color image to gray scale image (Figure 2 (B)). Figure 2 (C) shows the result of Canny edge operator. As shown in the result of edge detection, the extracted edges are not geometrically closed. Therefore, we connected the edges to acquire geometrically closed objects like Figure 2 (D). After that, we reversed the image to select the inner side of panels as region of interest (ROI). Finally, we cleared border connected objects to select only well extracted panel polygons.

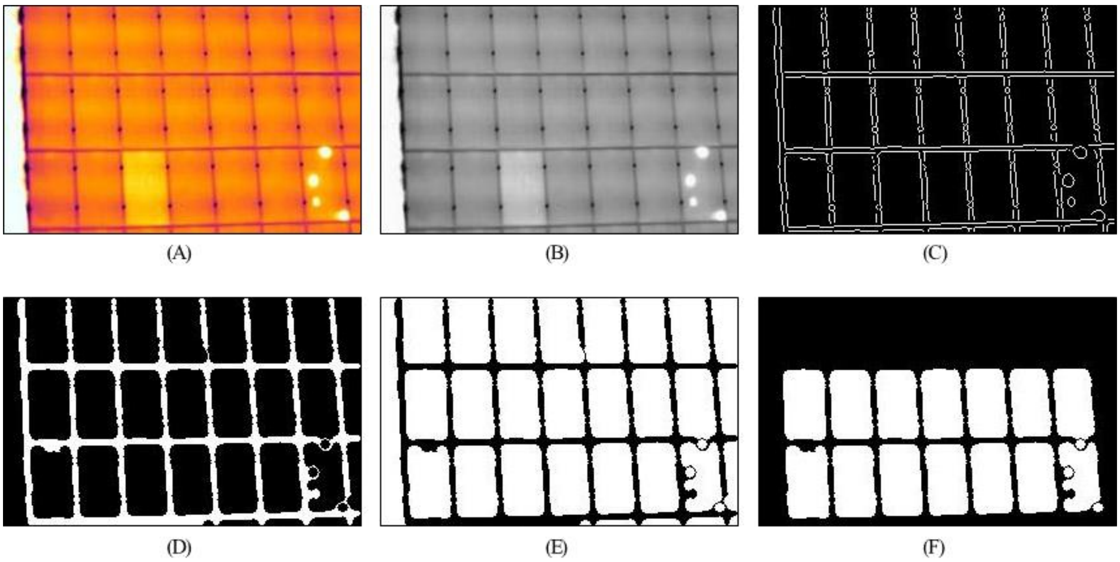

Figure 2. Panel area extraction process. (A) Selected area of thermal infrared image. (B) Gray scale converted image. (C) Applying Canny edge operator. (D) Closed geometry of Canny edge operator result. (E) Reverse conversion result. (F) Clearing border connected objects.

3. STATISTICAL CHARACTERISTICS OF PANEL INTENSITY

To examine individual statistical characteristics of panel intensity, we must acquire the boundaries of each panel. However, there are some circle shaped objects in the previous panel extraction result due to the hot spots in the original image. We eliminate these circles as shown in left image of Figure 3. With this ROI information, we can't select whole panel area. This means when we use Canny edge operator, noises in inner space of panels can be extracted as edges. And these edges will affect panel area extraction error significantly. Therefore, development of alternative algorithms are required to eliminate noises in inner space of panels. Fortunately, we can define more accurate panel area by using circumscribed rectangles of each panel's ROI area. In the right image of Figure 3, blue boxes shows the result of panel area definition.

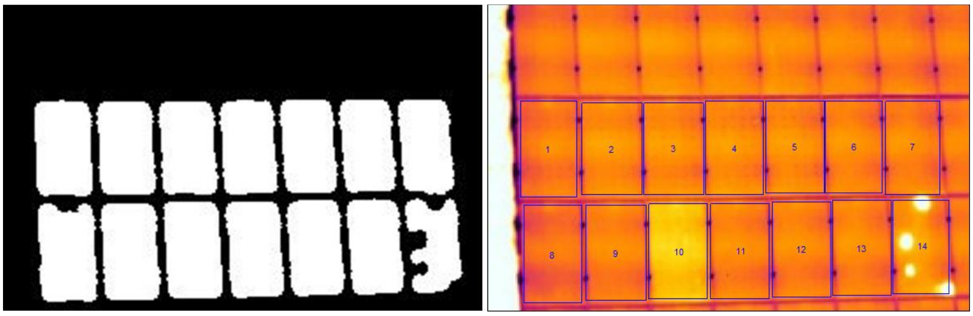

Figure 3. Final selected ROI (left) and panel area definition by using circumscribed rectangles of ROI area (right).

We compared the intensity histogram of each panel as shown in Figure 4. In Figure 4, green bar denotes intensity histogram. Blue line denotes mean intensity of all panels. Dashed blue line denotes 1σ range of all panels. Red diamond denotes mean intensity of the selected panel and red lines denote 1σ range of selected panel's intensity. We selected panel 9 and 13 as examples of normal condition panels. In case of normal condition panels, the histogram showed as normal distribution which is slightly skewed to the left. This means most of pixels have homogeneous intensity and there are no hot spots on the panel. In case of panel 10, the characteristics of histogram distribution was almost identical compared to the normal condition panels. However, its mean intensity was much higher than normal condition panels. It means there are no partial hot spots in panel 10, but it is suspected as a malfunction due to overheating. In case of panel 14, we could find that the distribution of histogram is wide and has multiple peaks. It means at least one hot spot will exist in this panel area. According to the result, malfunction panels show higher mean intensity value than normal condition panels. Therefore, we could find that the malfunction panel inspection is available when we use statistical intensity characteristics.

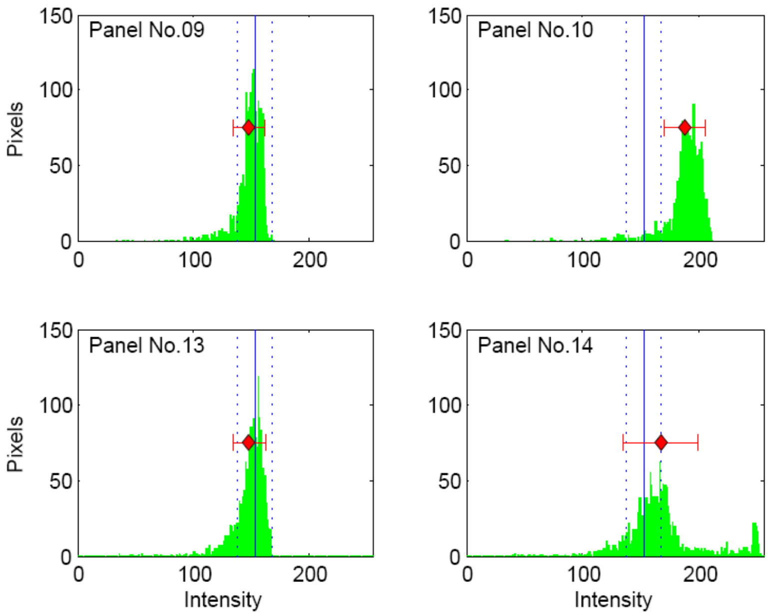

Figure 4. Intensity histogram and statistical characteristics of normal and malfunction panels.

4. CONCLUSION

In this study, we developed a panel area extraction algorithm based on Canny edge detection operator. According to the result of panel area extraction, we could find that this algorithm can determine the individual panel area although the edge of panel area is not linear. However, the noises which are located inner panel space affected ROI extraction error. Thus, the panel area extraction algorithm need to be improved.

For the statistical analysis of panel intensity, we defined panel area by using circumscribed rectangles of each panel's ROI area to avoid the ROI extraction error. According to the result of statistical analysis, the histograms and statistical values of malfunction panels clearly showed different distribution characteristics. Therefore, we determined that we proved the availability of this inspection method.

The panel area extraction algorithm and the malfunction detection method those developed in this research can be used as basic skills of automatic malfunction detection technology of PV module. For the development of fully automatic diagnosis system, additional related researches are necessary.

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