Photovoltaic panel anomaly detection system based on Unmanned Aerial Vehicle platform

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Abstract. The emergence and rapid development of the Unmanned Aerial Vehicle (UAV) Photovoltaic inspection system have become an effective means of solving the operation and maintenance of photovoltaic power plants. In order to cooperate with the current UAV platform for photovoltaic panel anomaly detection, this paper proposes a photovoltaic infrared target anomaly detection system. In this paper, the Sobel operator is used to extract the photovoltaic slab area of the image, and the canny operator is used to obtain the photovoltaic small plate area to realize the complementary advantages. At the same time, the deep learning is applied to the algorithm to learn the discriminative characteristics of the image, and the brightness statistics are used. The method is supplemented by the method to achieve anomaly detection of the photovoltaic panel area. The effectiveness of the proposed algorithm is proved by a large number of experiments.

1. Introduction

With the continuous development of the economy and society, clean energy, especially photovoltaic power plants, is playing an increasingly important role. As a large photovoltaic manufacturing and installed country, China creates profits by using photovoltaics to replace traditional power generation methods. However, the wide distribution, various types, low operating efficiency and long maintenance cycle of photovoltaic power plants [1] and some other reasons constrain the healthy development of photovoltaic power plants.

The emergence and rapid development of the UAV photovoltaic inspection system [2] has become an effective means of solving the operation and maintenance of PV power plants. In order to cooperate with the current UAV platform for photovoltaic panel anomaly detection, this paper proposes a photovoltaic infrared target anomaly detection system.

Our main contributions are as follows:

Multi-operator fusion. The Canny operator[3] can directly obtain the binary image of the edge, but can not provide a more reasonable straight edge; sobel operator can get the real natural object edge, but there is no binarization. In this paper, the Sobel operator[4] is used to extract the image of the photovoltaic slab, and the canny operator is used to extract the image of the photovoltaic slab to achieve complementary advantages.

Deep learning method assisted with traditional method. Traditional methods are susceptible to a given threshold, which can result in some low-dark stripes or plaques that are not detected, and they are too low to introduce non-abnormal regions. This paper takes the deep learning [5] method as the theme and uses the traditional method as the assistant to realize the detection of abnormal regions.
2. Related Works

F. Grimaccia [6] et al. designed a system that utilizes UAV aerial photography to inspect photovoltaic module failures, and proposed two different performance UAVs equipped with different imaging devices for coarse and fine detection: First use a gas-powered UAV with a large cruising radius for “rough patrol”, then send a light-duty UAV with a small cruising radius to the fault area for “fine identification”, and use a digital camera to capture visible light images to determine whether it is true failure, and the type of fault. Pia Addabbo [7] et al. used an unmanned aerial vehicle platform equipped with an infrared thermal imager to patrol the faults of the photovoltaic array, and proposed a method for integrating platform geographic information data and the results of the photovoltaic template matching algorithm in computer image processing[8].

3. Method

Canny operator as a classic edge detection algorithm can directly obtain the binary image of the edge, but its twisted lines can not provide a more reasonable straight edge in this step; Sobel operator can get the real natural object edge, but there is no binarization or it is 0-255 gray transition interval. In order to improve the accuracy of UAV detection of photovoltaic panel anomalies, this paper combines the Sobel operator with the canny operator, using the Sobel operator to extract the horizontal and vertical edge features, and using the Canny operator to calculate and fill the vertical and horizontal directions. The distance between adjacent pixels is the distance between the two pixels, which complements the advantages between the two operators. At the same time, the abnormality area of the photovoltaic panel is detected by the CNN model[9] training method assisted with brightness statistical method, as shown in Fig. 1.

![Photovoltaic panel anomaly detection system](image)

Fig. 1. Photovoltaic panel anomaly detection system

A. Image preprocessing

The original image data obtained from the infrared camera are 16-bit high dynamic range infrared images with a range of approximately 6000-9000. The original image data need to be remapped to a pixel range of 0-255, and the subsequent image can be normally performed and dealt with.

\[ x_{\text{new}} = \frac{x_{\text{old}}}{M} \times 255 \]  \hspace{1cm} (1)

In the middle, \( x_{\text{old}} \) is the pixel of the original image, and \( x_{\text{new}} \) is the pixel of the mapped image, and \( M \) is the maximum value in the original image.

B. Sobel operator obtains photovoltaic slab

1) LSD algorithm extracts line features

When the UAV photographs the photovoltaic panel, it is difficult to keep the photovoltaic panel in parallel, and the algorithm can process the image, and if the photovoltaic panel is parallel, the complexity of the algorithm can be less. In order to get the linear line of the image, the line detection algorithm used in this paper is the LSD algorithm[10]. The LSD algorithm consists of several strip descriptors \( BD_j \):

\[ LBD = (BD_1^x, BD_2^x, ..., BD_m^x)^T \]  \hspace{1cm} (2)
$BD_j$ is represented by the average vector $M_j$ of the strip descriptor matrix $BDM_j$ and the standard variance vector $S_j$. Therefore, $BD_j$ can be described as:

$$BD_j = (M_j^T, S_j^T)$$ (3)

$BDM_j$ is a stripe descriptor matrix obtained by accumulating gradient information of all the rows associated with the stripe. This article summarizes the gradient data in four directions: $d_\perp$, $d_{\perp}^{\text{opposite}}$, $d_{\parallel}$, and $d_{\parallel}^{\text{opposite}}$. $d_{\parallel}$ indicates the direction in which the line is oriented, $d_\perp$ indicates the clockwise vertical direction of $d_{\parallel}$.

In the formula:

$$BDM_j = \begin{pmatrix}
  v_{1j}^1 & v_{1j}^2 & \ldots & v_{1j}^n \\
  v_{2j}^1 & v_{2j}^2 & \ldots & v_{2j}^n \\
  v_{3j}^1 & v_{3j}^2 & \ldots & v_{3j}^n \\
  v_{4j}^1 & v_{4j}^2 & \ldots & v_{4j}^n
\end{pmatrix}$$

Among them, $g$ is the pixel gradient in the image coordinate system, and $g'$ is the pixel gradient in the local coordinate system. $\lambda$ is the Gaussian coefficient, and consists of local weight coefficient $f_l(k)$ and global weight coefficient $f_g(k)$.

$$\lambda = f_l(k)f_g(k)$$ (6)

2) **Get the angle of rotation**

According to the line angle information counted by the LSD algorithm, the linear direction of the current image line can be obtained. To make the photovoltaic panel parallel to the image, the image is rotated according to the linear angle obtained by the LSD algorithm.

$$x_{new} = f(x_{rot}, LBD)$$ (7)

Among them, $x_{new}$ is the rotated image, and $f(*)$ is a rotation function.

3) **CNN model for detecting photovoltaic panels**

The detection of photovoltaic slabs is a key step in the detection of photovoltaic panels. The general image detection bounding box is a vertical square. If the angle of the photovoltaic panel is not parallel or perpendicular to the image, the resulting bounding box will take a large number of non-photovoltaic panel areas. Increase false alarms for anomaly detection. In this paper, by rotating the image, the photovoltaic panel is parallel to the image, and the detection accuracy of the photovoltaic panel also increases. At the same time, the image is identified by the CNN model, and the position of the photovoltaic panel in the image is detected, thereby obtaining the region of the photovoltaic large panel.

$$\delta_{big} = \text{ran}(x_{new}, B)$$ (8)

In the middle, $\delta_{big}$ is the area of the photovoltaic slab, and $B$ is the position of the photovoltaic panel detected by the CNN model, and $\text{ran}()$ is the area detection function.

C. **Canny operator obtains photovoltaic small board**

Due to various effects of sensor, frame rate, flight speed and focal length under infrared conditions, the straight line to obtain a small photovoltaic panel is not feasible under a large number of verifications, and many image edges are blurred. In response to this problem, considering the dense lines of the canny operator, we can outline the complete photovoltaic panel edge of each small piece. This paper proposes to use the canny operator to extract the photovoltaic small plate in the image, as shown in Fig. 3.
1) **Get a blank area**

A large number of tests and observations have found that the photovoltaic panel area has very good smoothness, that is, there is no edge feature, and the photovoltaic panel area is empty. As shown in Fig. 3(b), the canny operator which performs poorly in the linear feature extraction is more able to outline the complete photovoltaic panel edge of each small piece because of the fine denseness of the lines. The noise area is connected together by a self-contained space expansion method because the photovoltaic panel area has no textured edges and it remains "clean" at all times.

![Canny operator](image)

![Binary negation](image)

![Complete photovoltaic panel edge](image)

**Fig. 2.** Canny operator obtains photovoltaic small board

2) **Get photovoltaic small board**

By expanding the columns of noise, the rows are expanded, so that the noise regions are connected, and the photovoltaic plate region is highlighted by the method of binarization and inversion, as shown in Fig. 3(c).

The image is rotated in order to make the area of the photovoltaic panel in the image parallel to the image. According to the characteristics of the canny operator, the area where the pixel is 1 in the image is the photovoltaic plate area:

\[
\delta_{\text{small}} = h(x_{\text{new}}, s)
\]

In the middle, \(\delta_{\text{new}}\) is the photovoltaic small plate area, and \(h(*)\) is a function to extract the area of the photovoltaic small plate according to the size \(s\) of the photovoltaic small plate.

**4. Experiments**

**A. Line detection algorithm**

The line detection algorithm is a line segment detection algorithm designed to obtain higher precision line segment detection results in a shorter time. The current line detection methods are HoughPLine [11], CannyLine [12], LSD [13]. In order to get the most suitable line detection algorithm, the detection performance of each detection algorithm is verified.

![Comparison of straight line detection results of each algorithm](image)

**Fig.3** Comparison of straight line detection results of each algorithm

It can be seen from Fig.3 that the HoughPLine algorithm has the problem that its parameters are not easy to select. It can only obtain the largest and longest continuous line on the image, and cannot obtain more detailed lines. It is based on the statistical method of the intersection point of the hypothetical point of the hypothetical point. It is not based on the edge geometry of the image itself, first excluded; although the CannyLine algorithm has fewer lines from the edge of the line, the statistical
characteristics are lower in the subsequent angle judgment; in comparison, the LSD algorithm can be stable. Photovoltaic panel direction information is in line with the requirements of this article.

B. High heat detection algorithm comparison

The purpose of this paper is to measure whether the photovoltaic panel is hot or not by the pictures taken by the UAV, and then detect the fault and troubleshoot. The better methods currently available are the bright statistics method and the training method. The bright statistical method is a traditional anomaly detection method, which aims to identify the high heat through the pixels of the image. The training detection method is a detection method with the rise of deep learning. The training of the deep network is realized by a large amount of data, so that the features extracted by the network are highly discriminative. In this paper, three anomalies are selected, and the anomaly detection is performed by the bright statistical method and the training detection method respectively. The results are shown in the figure.

![Statistical method for detecting hot spot results](image1)

![Training method to detect hot spot results](image2)

Fig. 4. Abnormal condition test result

It can be seen from Fig. 4 that by detecting the three abnormalities, both the statistical method and the training detection method can detect the abnormal hot spot area, and the accuracy of the training statistical method is higher than the statistical method in terms of the detection effect.

C. Overall analysis

Since the luminance statistical method is limited by the given threshold, although the grayscale image is equalized in this paper, if the threshold is too high, some low-dark stripes or plaques will not be found. If the threshold is too low, then introduce non-abnormal areas. Therefore, this paper takes the training detection method as the main body and uses the brightness statistical method as an aid to perform anomaly detection.

1) Analysis of photovoltaic large board inspection model

The performance of the training method is related to the number of training samples. In order to obtain a higher recognition rate, the number of training samples in this paper is 2,441, and the test results are shown in the table.

| Analysis of photovoltaic large board inspection model | AP(Average Precision) | mAP (mean Average Precision) |
|------------------------------------------------------|------------------------|-------------------------------|
|                                                      | 90.91%                 | 90.91%                        |

It can be seen from the table that the detection performance of the training detection method on the photovoltaic large plate reaches 0.9091 on the AP and 0.9091 on the MAP, which realizes the accurate detection of the photovoltaic large plate area.

2) Analysis of Photovoltaic Anomalous Hot Spot Detection Model

In order to verify the accuracy of the detection of abnormal conditions in this paper, the paper verifies the three conditions of spot, zero current and light bar respectively. The number of training test
samples used is 5477 and the number of abnormal images is 1798. The test results are shown in the table.

It can be seen from the table that the accuracy of the detection of the three anomalies in this algorithm is high and meets the requirements of the application.

| abnormal situation | AP (Average Precision) | mAP (mean Average Precision) |
|--------------------|------------------------|-------------------------------|
| Spot               | 98.62%                 | 92.71%                        |
| Zero current       | 95.69%                 | 92.71%                        |
| Light bar          | 83.81%                 | 92.71%                        |

5. Conclusion

In order to cooperate with the current UAV platform for PV panel anomaly detection technology, this paper proposes a PV infrared target anomaly detection system. In this paper, the Sobel operator and the canny operator are used to obtain the photovoltaic slab and the photovoltaic small plate respectively, and then the photovoltaic panel area is combined, and then the training detection method is mainly used. The brightness statistical method is supplemented to realize the abnormal detection of the photovoltaic panel area. The effectiveness of the proposed algorithm is proved by a large number of experiments. However, there are still some difficulties in the algorithm of this paper, such as the lack of samples of photovoltaic panel missing, and the inability to carry out relevant research, which is the focus of the next step.

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