Study on Hot Spot Detection Algorithm based on K-Means

Chenghao Deng¹, Yu Shen¹ and Kanjian Zhang¹, *

¹ School of Automation, Southeast University, Nanjing, 210018, China

Corresponding author: *kjzhang@seu.edu.cn

Abstract. Solar energy is a widely used clean energy at present, and it is inexhaustible. As the main power generation device, photovoltaic modules play an important role in solar power generation. Among the various abnormalities of photovoltaic modules, the hot spot effect will not only reduce the power generation efficiency of photovoltaic modules, but even cause fires due to high temperatures. In this paper, k-means algorithm is adopted for photovoltaic hot spot detection. K-means is an unsupervised machine learning clustering algorithm, which clusters the pixel points of the image, and extracting the connected domain with the points with the shape similar to rectangular rectangle in the clustering, that is, obtaining the hot spot area. At the same time, this paper also uses the traditional computer vision MSER algorithm for experiments, compares the MSER algorithm with the K-means algorithm, and draws the conclusion that the traditional computer vision algorithm has low accuracy but high speed. Machine learning algorithms are accurate but fast.

1. Introduction

Energy is a key element of development, economic growth, automation and modernization. In order to lead an advanced lifestyle, with economic development and rapid population growth, human society’s demand for energy is rapidly increasing. Globally, energy use and demand are increasing. Most energy demand forecasts indicate that current and expected energy sources are not sustainable. On the contrary, conventional energy systems are the main cause of many dangerous environmental problems, such as carbon dioxide emissions, global warming and acid rain. Therefore, it is necessary to develop sustainable and environmentally friendly energy, especially solar photovoltaic (PV) technology, to adapt to the protests of energy shortage and environmental pollution. Nowadays, the rational use of renewable energy has become an extremely important issue. The adverse effects of conventional energy on the environment and the depletion of some of these resources have aroused great interest in the use of non-polluting, renewable and site-independent energy sources (such as solar energy). Photovoltaic technology is the fastest growing technology in the world. Photovoltaic conversion is the direct conversion of the inexhaustible sunlight in the world into electrical energy except with the help of machines or any mobile equipment[1]. Since the photovoltaic system has no moving parts, it requires minimal maintenance and can be used for a long time. The design of photovoltaic elements is rough and simple. Their important facility is to construct them as independent systems to provide output from micro power to high power. So they can be used for power supplies, water pumps, remote buildings, solar home systems, communications, satellites and space vehicles. Solar energy is one of the renewable energy sources. In the future energy system, solar energy will be able to contribute to the security of energy supply. By using solar photovoltaic energy systems, greenhouse gas emissions can be greatly
reduced. However, the solar power generation system has many failures, such as hot spots. Hot spots will not only reduce the power generation efficiency, but also cause fires in serious cases.

This paper proposes two detection methods based on infrared imaging image analysis. The first uses the traditional computer vision method MSER algorithm; the second uses machine learning unsupervised clustering algorithm.

The first traditional computer vision algorithm is the MSER algorithm based on the watershed algorithm[2][3]. The MSER algorithm is to perform binarization processing on a grayscale image, and the binarization threshold value increases sequentially from 0 to 255. In all the binarized images obtained, if some connected domains in the image change very little or there is no change. Then this area is defined as the maximum stable extreme value area. For infrared pictures of photovoltaic modules, the brightness of the infrared area is significantly higher than other areas due to the hot spot. Therefore, after passing the MSER algorithm, the maximum stable extreme value area is the hot spot area.

The second is the unsupervised clustering algorithm K-Means segmentation algorithm based on machine learning [4][5]. That is, the brightest ROI is extracted as the algorithm for detecting the target. This method clusters the pixels of the image through the K-means algorithm. Because the hot spots of photovoltaic modules are mostly rectangular. Therefore, the connected domain can be extracted from the points in the cluster that are similar in shape to the rectangular rectangle, and this area is the photovoltaic hot spot area.

2. MSER algorithm

2.1. MSER Principle
MSER (Maximum Stable Extreme Value Region)[6], its concept can be explained by the following imagination. Imagine all possible thresholds for a grayscale image. We call the pixels below the threshold black, and those above or equal to white. We imagine this picture is in front of us, the threshold gradually increases from small to large[7]. At the beginning, the image should be all white. As the threshold increases, there will be areas that will become black due to the change of the threshold, and more and more, eventually all black. In this case, it is very similar to us watching a movie. One is composed of many frames. The set of movie frame combinations is the maximum area set[8]. If we change the size of the threshold and the speed and time of the projection, this area will get a minimum area.

From another perspective, the area to be detected must be a whole. For a whole, its pixel value will only change greatly with its surrounding environment, but it is roughly the same internally, at least gradual, and it is impossible to jump.

3. K-Means clustering algorithm

3.1. K-means algorithm
For a given sample set, K-Means divides the sample set into K clusters according to the distance between the samples, so that the points in the clusters are connected as closely as possible, and the distance between the clusters is relatively large.

We assume that the input cluster is divided into $(C_1, C_2, ..., C_k)$, then the ultimate goal is to minimize the square error $E = \sum_{i=1}^{k} \sum_{x \in C_i} \|x - \mu_i\|^2$ where $\mu_i$ is the mean vector of the cluster $C_i$, also called the centroid, the expression is as follows: $\mu_i = \frac{1}{|C_i|} \sum_{x \in C_i} x$.

The overall process of the algorithm is as follows: the input sample set is $D = \{x_1, x_2, ..., x_m\}$, the cluster tree of clustering is k, and the maximum number of iterations is N. The output is the cluster partition $C = \{C_1, C_2, ..., C_k\}[9][10][11]$. 
4. Experiment procedure

4.1. Experimental data
The experimental picture data is obtained from the database of Wuxi Suntech Power Co., Ltd. The experimental picture is the infrared thermal imaging picture of the photovoltaic module synthesized by Wuxi Suntech through the fusion mode method, Figure 1.

![Photovoltaic original picture](image)

**Figure 1.** Photovoltaic original picture.

It can be seen from the picture that the temperature of one cell in this photovoltaic module is significantly higher than that of the other cells. In the figure, the image of this cell is obviously brighter than the other cells. According to reality, this part that is obviously brighter than other cells is the hot spot area. The long-term existence of this hot spot area will damage the power generation of the entire photovoltaic panel and reduce the service life and power generation efficiency of the entire photovoltaic panel. Therefore, the detection of such hot spots is very important for operation and maintenance personnel.

4.2. MSER experiment
MSER is the area of maximum stable extreme value. The algorithm binarizes the gray image, and the threshold value increases from 0 to 255. The increase of the threshold is similar to the rise of the water surface in the watershed algorithm. In all the binarized images obtained, some connected domains in the image have little or no change, then the area is the MSER area.

The entire MSER algorithm is roughly divided into three parts, data pre-processing, traversing pictures, and judging the MSER area.

4.2.1. data pre-processing. In the data pre-processing, it first records whether each pixel has been explored, the direction of exploration, and the direction of exploration. Next, the number of all gray values will be calculated, and the stack size will be allocated according to the number of different gray values. Then allocate memory and record the history of threshold changes.

4.2.2. traversing pictures. The process of traversing the picture is mainly to traverse the binarization threshold from 0-255 and record it. Step1 set the gray value of the first block to 256. This gray value actually does not exist and is used to determine whether the program is over. Step2 Set the second block as the gray value of the first pixel of the input image and initialize the block, and mark the pixel as visited at the highest position. Step3, cyclically search in the 4 neighborhoods to increase the binarization threshold water level and record it in the stack.

4.2.3. Judging the MSER area. The change of a MSER region mainly depends on the magnitude of the change of the connected domain during the binarization process. Therefore, the main method of judgment is as follows, whether the area difference of a certain connected domain meets certain conditions.
\[ R_{th} \text{ is the number of pixels in the last historical parent area, } R_{lf} \text{ is the number of pixels in the last stable parent area,} \]
\[ \eta = \frac{R_{th} - R_{lf}}{R_{lf}} \]  
(1)

4.2.4. MSER experiment effect. We select 100 pictures of Wuxi Suntech Power Co., Ltd. and use mser algorithm to process the picture. As the result, it is found that many areas that are not hot spots are identified. For actual photovoltaic modules, these are not hot spots and are misdetected. Regarding the actual photovoltaic area in the picture, it can be found that when the shooting angle and distance are fixed, the hot spots of the photovoltaic module actually belong to a small rectangle close to a square. Therefore, we can filter out those rectangles with a large difference in length and width, and get the following results in Figure 2.

![Figure 2. MSER effect](image)

It can be found that a good recognition effect is obtained. There are a total of 100 pictures in the database, 15 of which have no hot spots. According to the MSER algorithm, 80 pictures with hot spots were detected out of 85 pictures with hot spots, and 13 pictures without hot spots were detected in the remaining 15 pictures without hot spots. Overall effect deviation.

4.3. K-means experiment

The K-MEANS algorithm is an iterative clustering analysis algorithm. It first selects K points as cluster centers in advance, and then continuously calculates new cluster centers according to the iterative algorithm until the cluster centers no longer change. Since new cluster centers need to be recalculated in each iteration, the convergence speed of this algorithm is relatively slow.

4.3.1. K-means experiment procedure. The experimental data also used 100 hot spot pictures obtained by Wuxi Suntech Solar Co., Ltd. through the fusion mode method. The overall experimental procedure is as follows.

- Step 1: convert BGR image to RGB image;
- Step 2: extract the pixel matrix in the image
- Step 3: if the number of iterations is less than 100 or the error is less than 0.2, skip to step 4, otherwise skip to step 5
- Step 4: K-means algorithm calculates cluster centers and skip to step 3
- Step 5: find the brightest cluster center
- Step 6: got hot spot area

For each picture, first convert the image from BGR channel to RGB channel and extract the pixels of the picture as matrix p(76800*3). First, the infrared images of photovoltaic modules are clustered by K-means clustering algorithm, and the pixels in the portrait are grouped into 10 categories according to RGB values, as shown in Figure 3
Figure 3. K-Means cluster map

It can be found from Figure 3 that many pixels have been clustered into one category after clustering, but what we need to find is the hot spot area. The brightness of the hot spot area will be higher than that of the surroundings, which is the category with the highest brightness, that is, the largest average RGB value in the image. Extract the category with the largest RGB average value as the hot spot to be inspected, as shown in Figure 4.

Figure 4. Extract RGB mean maximum class

Figure 5. Filter interference annotation

What is extracted from Figure 5 is not only the hot spot area, but also some interference areas. These are mainly due to the annotations made by the camera itself during the imaging of infrared thermal imaging, and for the same infrared thermal imager, these interference annotations. The position is fixed, so the pixels in these fixed areas can be filtered directly by filtering, as shown in Figure 6.

From Figure 6, it can be found that there are still many interference areas. Because the hot spots of photovoltaic modules are mostly rectangular and the area is not too small, the connected domain can be analyzed, and the pixels with less than 100 pixels and not long. The connected domain of the square rectangle can extract the hot spot area, and the result is shown in Figure 6.

Figure 6. Hot spot detection map

Figure 7. Infrared image of normal components
The above work can basically detect the hot spot, but sometimes the brighter area in the normal component is mistaken for the hot spot. Figure 7 shows the infrared image of the normal component. The high-brightness area in the lower right corner of the figure is due to the shooting distance. Caused recently. Because the infrared thermal imager has a certain temperature measurement error due to different shooting distances, it is not a real hot spot.

Therefore, a method for automatically identifying the temperature difference of the module and predicting the normal/hot spot of the photovoltaic module is proposed.

4.3.2. Pre-classification of components based on temperature. According to the temperature difference of components, they are divided into three categories: temperature difference is less than 10°C, classified as normal components, as shown in Figure 8; temperature difference ≥10°C, less than 20°C, classified as slight hot spots, as shown in Figure 9; temperature difference ≥20°C, Classified as severe hot spots, as shown in Figure 10.

The Tesseract-OCR is used to automatically identify the temperature in the upper right and lower right corners of the graph. Tesseract-OCR is an optical character recognition software open sourced by HP in 2005 and maintained and upgraded by Google since 2006. It can realize character recognition in multiple languages and digital recognition in multiple fonts. We adopted the latest version based on the LSTM model in 2019. However, directly using the original model to identify the numbers in the picture is not good. Therefore, a part of the training samples (100 infrared images, automatically cut out the black boxes showing the temperature numbers in the upper right and lower right corners), use jTessBoxEditor to label the samples.

Through the above method, a good recognition effect can be obtained. There are a total of 100 pictures in the database, 15 of which have no hot spots. According to the K-MEANS algorithm, 83 pictures with hot spots are detected in 85 pictures with hot spots, and 14 pictures without hot spots are detected in the remaining 15 pictures without hot spots. The accuracy rate reaches 97.6%. The final hot spot detection effect is shown in Figure 11.
4.4. Experiment comparison
The detection accuracy and process time speed of the two algorithms are shown in Table 1.

| Algorithm | Hot spot detection accuracy rate | Not hot spot detection accuracy rate | Processing time speed |
|-----------|----------------------------------|--------------------------------------|-----------------------|
| Mser      | 94%                              | 87%                                  | 0.1s                  |
| k-means   | 97.6%                            | 93.3%                                | 1.5s                  |

It can be found from the table that the computer vision mser algorithm is obviously not as good as the k-means algorithm. However, it can be found from Table 1 that the traditional computer vision Mser algorithm is significantly faster than the K-Means algorithm. Therefore, if the speed requirement is higher than the accuracy in the hot spot detection, the Mser algorithm can be selected, otherwise the K-Means algorithm can be selected.

Acknowledgement
This work was supported by the National Key Research and Development Program of China(Grant No.2018YFB1500800).

Reference
[1] Hosenuzzaman, M., Rahim, N.A., Selvaraj, J., Hasanuzzaman, M., Malek, A.B.M.A. & Nahar, A., Global prospects, progress, policies, and environmental impact of solar photovoltaic power generation. Renewable and Sustainable Energy Reviews, 2015. 41: p.284–297.
[2] L. Neumann, J. Matas, On combining multiple segmentations in scene text recognition, in: Proceedings of the ICDAR, 2013, pp. 523–527.
[3] Wu V, Manmatha R, Riseman E M. Finding text in images[C]// Digital Libraries. 1997:3-12.
[4] Local and global approaches of affinity propagation clustering for large scale data[J]. Ding-yin XIA, Fei WU, Xu-qing ZHANG, Yue-ting ZHUANG (School of Computer Science and Technology, Zhejiang University, Hangzhou 310027, China). Journal of Zhejiang University (Science A: An International Applied Physics & Engineering Journal). 2008(10)
[5] Fast affinity propagation clustering: A multilevel approach[J]. Fanhua Shang, L. C. Jiao, Jiarong Shi, Fei Wang, Maoguo Gong. Pattern Recognition. 2011 (1)
[6] L. Sun, Q. Huo, An improved component tree based approach to user-intention guided text extraction from natural scene images, in: Proceedings of the ICDAR, 2013, pp. 383–387.
[7] Y.-F. Pan, X. Hou, C.-L. Liu, A hybrid approach to detect and localize texts in natural scene images, IEEE Trans. Image Process. 20 (3) (2011) 800–813.
[8] L. Kang, Y. Li, D. Doermann, Orientation robust text line detection in natural images, in: Proceedings of the CVPR, 2014.
[9] Cure: an efficient clustering algorithm for large databases[J]. Sudipto Guha, Rajeev Rastogi, Kyuseok Shim. Information Systems. 2001 (1)
[10] BIRCH: A New Data Clustering Algorithm and Its Applications[J]. Tian Zhang, Raghu Ramakrishnan,Miron Livny. Data Mining and Knowledge Discovery. 1997 (2)
[11] Adaptive B-splines and boundaryestimation. Figueiredo M A T, Leitao J M N, Jain A K. IEEE Computer Society Conference in Computer Vision and PatternRecognition. 1997