Infrared image-based detection method of electrical equipment overheating area in substation

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Abstract. For the detection of overheated areas of electrical equipment, in order to accurately segment out the overheated areas and reduce the fault detection range, this paper proposes a new overheated area detection algorithm. Firstly, the Otsu algorithm is used to remove the background and segment the general area of the electrical equipment area; secondly, the active contour model is used to refine the edge of the target area to remove the redundant edge points; finally, FCM clustering algorithm is used to suppress over segmentation and accurately divide the overheated area. The experiment proves that the algorithm can accurately divide the overheated area, and has certain practical value.

1 Introduction

According to the survey, about 70% of power system failures are caused by electrical equipment failures, and about 50% of them are caused by overloads, unbalanced loads, and component aging^[1]. The failure of electrical equipment will not only affect the safe and stable operation of the power system, but also bring a huge economic burden for subsequent failure maintenance. Therefore, it is of great significance to study the overheated area state detection technology of electrical equipment and predict the impending failure of the equipment to ensure the safe and stable operation of the power system and reduce the economic losses caused by the failure.

At present, the detection of the overheated area mainly uses image segmentation technology to segment the overheated area, and then determine the thermal fault according to the classification criteria set subsequently. Among them, the most important step to accurately find the overheated area has a decisive influence on the subsequent classification and judgment operations. Many scholars have conducted a lot of research on the segmentation of infrared images of electrical equipment. In reference [2], Otsu algorithm is used to segment the seed region, and then the region growing algorithm is used to segment the fault area of power equipment; In reference [3], through simplifying the data set, optimizing clustering, and using Gaussian function to improve the membership of FCM algorithm, the target area of power equipment is segmented. In reference [4], aiming at the problem that the image contrast in the

infrared image of high voltage transmission line insulator is not strong, the improved minimum within class absolute difference criterion is introduced into the traditional PCNN image segmentation algorithm, and the optimal segmentation threshold is determined by the criterion. In reference [5], watershed algorithm and fuzzy clustering method are used to segment the target region of infrared image. In reference [6], a region growing method based on pixel value pseudo color processing is proposed. This method can completely segment the target region from the background, but it has the problem of over segmentation.

This paper takes the overheated area of electrical equipment as the research object and combines the characteristics of infrared images of electrical equipment, and proposes a segmentation method combining Otsu algorithm, active contour model and FCM clustering algorithm. Firstly, the Otsu algorithm is used to remove the background and segment the general area of the electrical equipment; secondly, the active contour model is used to refine the edge of the target area to remove the redundant edge points; finally, FCM clustering algorithm is used to suppress over segmentation and accurately divide the overheated area.

2 Algorithm theory

2.1 Otsu algorithm

First use the Otsu algorithm to pre-segment the image, remove the background interference to obtain the target area of the electrical equipment. The Otsu^{[7][8]} algorithm

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is to find an optimal threshold T to divide the image into the foreground and the background, so that the variance between the classes between the background and the foreground is the largest. If the number of pixels in an image is $M \times N$ and the number of pixels with gray value i is n_i , the probability p_i of pixel gray value i can be expressed as follows:

$$p_i = \frac{n_i}{M \times N} \quad (2-1)$$

According to the idea of Otsu method, the image can be divided into target CF (CF=t+1,2,...,255) and background CB (CB=1,2,...,t) according to the size relationship between the image gray value [0, L-1] and the gray threshold t , when the variance between the foreground and the background is maximum. The obtained threshold is the optimal threshold T , namely:

$$T = \text{Arg} \max_{0 \leq t \leq L-1} \{P_F P_B (\mu_F - \mu_B)^2\} \quad (2-2)$$

Among them, P_F and P_B are the probability of foreground and background, μ_F and μ_B are the variance of foreground and background.

From this, the best threshold for dividing the image into foreground and background can be found. Through the above Otsu algorithm, the image can be easily divided into the target and the background with the probability of misdivision, but the accuracy needs to be improved.

2.2 Active contour model

Although the traditional threshold segmentation method can quickly segment the target area, the edge of the segmentation result is relatively rough. Therefore, in this paper, the active contour model is used to modify the edge after segmentation by Otsu algorithm, so as to eliminate the influence of some redundant edge points on the subsequent segmentation, and get the target area with smooth edge.

Active contour model [9], also known as "Snakes", this algorithm can obtain continuous, smooth and relatively accurate closed segmentation boundary, and can also obtain a good segmentation effect under high noise conditions. The principle of the algorithm is to convert the image segmentation problem to the energy functional minimum problem to solve. In the process of solving the minimum value of the energy function, the contour curve is gradually driven to approach the edge of the object to be detected, and the final curve is close to the target edge. Infinitely overlap to divide the target.

The total energy of the active contour can be defined as:

$$E_{snake}(x) = \int_0^1 E_{Int}(X(s)) + E_{Ext}(X(s)) ds \quad (2-3)$$

In equation (2-3), $E_{Int}(X(s))$ is the internal energy function that generates internal forces, and $E_{Ext}(X(s))$ is

the external energy function that generates external forces. Both are function terms.

In the process of obtaining the minimum value of the total energy functional function $E_{snake}(x)$ of the active contour, according to the variational method, the minimum value of $E_{snake}(x)$ needs to satisfy the Euler-Lagrange equation:

$$\frac{\partial}{\partial s} \left(\alpha \frac{\partial X}{\partial s} \right) - \frac{\partial^2}{\partial s^2} \left(\beta \frac{\partial^2 X}{\partial s^2} \right) - \nabla E_{Ext} = 0 \quad (2-4)$$

To analyze the motion mechanism of the active contour from the perspective of physics and mechanics, formula (1-5) can also be expressed by a force balance equation:

$$F_{Int}(X) + F_{Ext}(X) = 0 \quad (2-5)$$

Among them, F_{Int} corresponds to the internal energy function $E_{Int}(X(s))$ in the total energy of the active contour, which represents the external force to control the elastic deformation of the active contour curve, which plays a role in maintaining the continuity and smoothness of the contour. $F_{Ext}(X)$ represents the external force that drives the active contour curve to approach the target edge, which corresponds to the external energy $E_{Ext}(X(s))$ in the active contour.

At this time, a virtual time parameter t is introduced. If the active contour curve X is regarded as a dynamically changing function A , the function of calculating the curve A can be expressed as:

$$\frac{\partial X}{\partial t} = \frac{\partial}{\partial s} \left(\alpha(s) \frac{\partial X}{\partial s} \right) - \frac{\partial^2}{\partial s^2} \left(\beta(s) \frac{\partial^2 X}{\partial s^2} \right) - \nabla \varepsilon(X(s)) \quad (2-6)$$

Equation (2-6) describes the dynamic change process of curve $X(s)$: with the increase of time t , the active contour curve continues to approach the edge of the target image under internal and external forces, and the curve function $X(s,t)$ also changes accordingly until $\frac{\partial X}{\partial t} = 0$, at this time, the internal and external forces have reached equilibrium, the active contour curve stops moving, and the total energy of the curve has also reached a minimum value, so that the active contour curve coincides with the target edge with the largest gradient, and the target contour is detected. However, the speed of the algorithm is slow, and the effect of the algorithm is related to the image feature distribution. If the active contour model algorithm is directly applied in the substation with a complex background, it may not get the ideal effect, and may even get the wrong result.

2.3 Fuzzy C-means clustering algorithm

After the electrical equipment target area is segmented by the above algorithm, the influence of surrounding

equipment has been removed, and the overheated area is also highlighted. Therefore, FCM algorithm^{[10][11][12]} is used to accurately divide the heating area to prevent over segmentation. Compared with k-means hard clustering, FCM clustering algorithm integrates the essence of fuzzy theory and provides more flexible clustering results. In most cases, the objects in the data set may belong to multiple clusters. If an object is rigidly divided into a cluster, it may cause classification errors. Therefore, fuzzy theory is to assign a weight to each object to represent the degree to which the object belongs to the cluster. The FCM algorithm can be used for image segmentation. It is a clustering iterative algorithm that can produce the optimal c partitions, the partition center $V = \{v_1, v_2, \dots, v_c\}$, the unlabeled data set $X = \{x_1, x_2, \dots, x_n\}$ represents the pixel intensity, and n is the number of image pixels. The objective function of FCM is as follows:

$$J_m(U, V) = \sum_{i=1}^c \sum_{k=1}^n u_{ik}^m d^2(x_k, v_i) \quad (2-7)$$

Where m represents the number of clusters in the cluster, $d(x_k, v_i)$ represents the distance between the pixel x_k and the cluster center v_i , and $\sum_{i=1}^c u_{ik} = 1$, $m \geq 1$ is defined.

The membership value u_{ik} is used to judge whether the pixel x_k belongs to a specific cluster, and the local minimization of the objective function $J_m(U, V)$ is achieved by repeatedly iterating the value of the membership u_{ik} and the clustering center v_i .

$$u_{ik} = \left[\sum_j^c \left(\frac{d^2(x_k, v_i)}{d^2(x_k, v_j)} \right)^{\frac{1}{m-1}} \right]^{-1} \quad (2-8)$$

$$v_i = \frac{\sum_{k=1}^n u_{ik}^m x_k}{\sum_{k=1}^n u_{ik}^m}, 1 \leq i \leq c \quad (2-9)$$

In the process of the objective function $J_m(U, V)$ being constantly minimized, the clustering center v_i also tends to be stable. The termination condition of the iteration is:

$$\max_{1 \leq i \leq c} \|v_i^t - v_i^{(t-1)}\| < \varepsilon \quad (2-10)$$

Where v_i^t is the new clustering center, v_i^{t-1} is the last clustering center, and ε is the iteration termination threshold. In this way, iterative iteration and judgment of the termination condition can achieve image segmentation.

3 Algorithm flow

For the infrared thermal image of substation equipment, a new detection method is adopted in this paper. Firstly, the infrared image is segmented by Ostu algorithm to remove the background interference and get the target area of electrical equipment. Then, the edge of the target area is modified by active contour model to remove the influence of redundant edge pixels. Finally, the overheated area is segmented by FCM algorithm. The specific algorithm flow of this paper is as follows:

(1) Segment electrical equipment to remove interference from background images

① Otsu algorithm is used to segment the overheated area of electrical equipment to remove the background interference, and get the electrical equipment target area with rough edge.

② The active contour is used to correct the edge of the segmented target area to remove the effect of removing excess edge pixels, and the target area image with finer edges is obtained.

③ The KCM algorithm is used to divide the overheated area accurately.

The detection flowchart of the overheated area of the electrical equipment in the substation is as follows:

Figure 1. Flowchart of detecting overheated area of electrical equipment.

4 Experimental results and analysis

In order to verify the superiority of the algorithm in this paper, different devices in different scenarios are selected for the experiment. The whole experiment process is divided into two parts. The first part verifies the rationality of the detection method in this paper, and conducts experiments according to the process; the second part verifies the superiority of the algorithm, which is compared with the Ostu algorithm and k-means clustering method.

(1) Results and analysis of detection methods in this paper

This section mainly takes the isolation switch blade as an example for verification. Figure 2 is the original infrared image of the isolation switch blade, as shown in the figure below.

Figure 2. The original infrared image of the isolation switch blade.

(a) Modification of Ostu segmentation algorithm by active contour model

In this paper, Ostu algorithm is used to segment the original image, extract the equipment area and remove the background interference, as shown in Figure 3 a). Since the edge of the target area obtained by direct segmentation using Ostu algorithm is rough, and it is easy to form small dots around the target area due to noise, this paper uses the active contour model to modify the edge of the target area after Ostu algorithm to remove the interference of small impurities. After the active contour correction, it is shown in Figure 3 b).

a) Ostu segmentation rendering.

b) Effect picture of active contour correction.

Figure 3. effect diagram of disconnecting switch knife edge segmentation.

(b) The effect of Ostu and segmentation on FCM algorithm

After pre segmentation, the electrical equipment target area is obtained, and the influence of surrounding equipment is removed, which is convenient for FCM to segment the overheated area more accurately. Figure 4 a) shows the segmentation result without pre segmentation, and Figure 4 b) shows the segmentation result after

image pre segmentation. It can be seen from the figure that there is interference from surrounding equipment by FCM algorithm without pre segmentation, and other hot spots may be segmented in, resulting in incorrect analysis of the operation status of each electrical equipment; while after pre segmentation, FCM algorithm segmentation can accurately divide the overheating area and eliminate the interference of other equipment.

a) Effect picture without pre segmentation.

b) Effect picture after pre segmentation.

Figure 4. FCM segmentation effect.

(2) The results of this method are compared with other algorithms

Three infrared images of power equipment, such as wire connector overheat map, insulator connection line overheat map and disconnecter head overheat image, are

selected as experimental data, and the Ostu threshold segmentation algorithm, K-means clustering segmentation algorithm and the segmentation algorithm

in this paper are used for experimental comparison. The results are shown in the following figure.

Figure 5. Original infrared image of electrical equipment.

Figure 6. Ostu segmentation rendering.

Figure 7. K-means segmentation rendering.

Figure 8. In this paper, the algorithm segmentation effect map.

As can be seen from the above segmentation results, using the Ostu algorithm to segment can only segment electrical equipment, and cannot highlight the segmented overheated area, and the target area image obtained after segmentation is greatly affected by noise, the edges are not smooth enough, and there are Spots are present, so it can be seen that Ostu cannot be used alone to detect overheated areas; The k-means clustering method can divide the overheated area of electrical equipment, but it does not accurately detect the real heating area. There is a certain degree of over-segmentation, and it is not suitable for detecting the overheated area of electrical equipment alone; Finally, observing the segmentation results of the algorithm in this paper, this detection

method can accurately segment the overheated area, narrow down the fault search range, can suppress the over-segment phenomenon to a certain extent and the edge of the overheated area obtained after segmentation is smooth, so the algorithm can be used For overheated areas.

5 Conclusion

This paper proposes a method for detecting overheated areas based on infrared images, which narrows the detection range of overheated areas and highlights the location of heat sources, which is helpful for workers to maintain electrical equipment more accurately and

reduces social costs and waste of human resources. This method first uses the Otsu algorithm to pre-segment the image and divide the area where the electrical equipment is located; then uses the active contour model to refine the edge of the target area and remove excess edge points; and finally uses the FCM clustering algorithm to suppress over-segmentation and accurately divide the overheated area. The algorithm can highlight the overheated area, but there are still certain errors, especially after the active contour model is used. The running time of the algorithm becomes longer. The algorithm also has a lot of room for improvement, such as using suitable enhancement algorithms to highlight overheated areas for easy segmentation; and using the watershed algorithm instead of Otsu for pre-segmentation.

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