

# Design and Implementation of Fault Region Segmentation Method for Transformer Heat Sinks

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**Abstract:** For the fault region identification of transformer heat sink, in order to accurately segment the abnormal region in the heat sink, this paper studies a new abnormal region segmentation method for transformer heat sink. Firstly, Gaussian filtering and 4-direction Laplace operator are used to preprocess the infrared image of the heat sink to get a cleaner image, which provides the basis for the subsequent fault region segmentation; then the FCM segmentation algorithm is used to pre-segment the image of the heat sink to remove the interference of the background, and to get the target region of the transformer heat sink with a rougher edge; finally, the region growth algorithm is used to finely divide the fault region of the heat sink to get a more accurate segmentation of the fault region of the transformer heat sink. Finally, the region growth algorithm is used to finely divide the faulty region of the heat sink to obtain more accurate different faulty regions of the transformer heat sink. After experimental verification, the segmentation method can accurately segment the different fault regions of the transformer heat sink, and has certain practical value.

**Keywords:** Heat sink, Image segmentation, FCM, Region growing method.

## 1. Introduction

With the rapid development of China in urbanization, informationization and new industrialization, the demand for electricity has grown significantly in various industries. Transformer as a power system transmission and distribution of important electrical equipment, in a long time, due to iron loss, copper loss and other losses will produce heat inside the transformer, which leads to the temperature of the transformer core, windings and other components of the temperature rise, which may cause the safe operation of the transformer. The transformer is mainly through the radiator to form the oil circulation, so that the oil is cooled by the radiator and then flow back to the oil tank, reduce the oil temperature inside the transformer, so that the transformer safe operation. However, with the transformer running for a long time, may be due to a variety of reasons lead to heat sink failure, corrosion, fracture, blockage and other problems, resulting in a decline in its heat dissipation effect, thus causing the internal temperature of the transformer is too high will have an impact on the efficiency of the entire transformer and its safety [1-2].

At present, the thermal defects of the transformer heat sink fault diagnosis, usually using infrared image detection technology [3]. The detection technology will be inspected by the temperature value of the equipment and the gradient of the temperature bar corresponds to each other, so that the color of the temperature bar can be lightened with the decrease in temperature or other transformations, to obtain a thermal distribution map reflecting the temperature of the object. Then you can have a sense of hierarchy through the thermal distribution map, that is, infrared images, for diagnosis and prediction of electrical equipment to provide the basis for the abnormal heat state.

At present, the main use of infrared thermal imaging technology for thermal imaging of transformer heat sinks, and then use image segmentation technology to segment the faulty area of the transformer heat sink, to determine whether there is a fault [4-5]. Therefore, for the segmentation of infrared

images of electrical equipment, many scholars have conducted a lot of research. Guo Shuangquan et al [6] used the improved SLIC algorithm to segment and mark the fault region of the disconnecting switch based on color space conversion to achieve efficient and accurate fault identification of the infrared image of disconnecting switch. Wu Xiaoxian et al [7] proposed an improved FCM segmentation method based on superpixel for infrared images of power equipment based on the SNIC superpixel algorithm and the idea of maximum interclass variance, which improves the segmentation efficiency based on improved under-segmentation and lays the foundation for fault diagnosis of power equipment at a later stage. L. Lei et al [8] utilized the local subordination filtering of spatial neighborhood instead of the spatial neighborhood The FCM algorithm is improved by using the distance between the pixels in the spatial neighborhood and the clustering center, which improves the robustness of the algorithm and the segmentation effect of the edge contour, but the algorithm can only segment the equipment contour but cannot locate the region. Wang Xiaofang et al [9] used Linear Spectral Clustering Algorithm (LSC) algorithm for super pixel segmentation of infrared images and combined Otsu algorithm and MSRM super pixel algorithm to realize the extraction of power equipment in infrared images. Wenpu Li et al [10] proposed an improved R3Det model for defective region segmentation for defect detection of porcelain jacket, the improved segmentation network can reduce the interference of complex background and diagnose the defects of voltage-induced thermogenic devices by temperature difference threshold method. Deng Changzheng [11] and others improved DeepLabV3+ network by means of lightweighting and attention mechanism, which solved the problem of low accuracy and time-consuming segmentation of infrared images of power equipment under complex background.

Therefore, in this paper, a dual segmentation method based on FCM and region growing method is investigated from the anomalous region segmentation of transformer heat sink.

Firstly, a relatively clean image is obtained through image preprocessing operation to provide a basis for subsequent fault region segmentation; then the FCM segmentation algorithm is utilized to pre-segment the heat sink image to remove the interference of the background and obtain the target region of the transformer heat sink with a relatively rough edge, and finally the region growth algorithm finely delineates the faulty region of the heat sink to obtain the different faulty regions of the transformer heat sink in a more accurate way.

## 2. Algorithm Theory

### 2.1. FCM Segmentation Algorithm

In the process of heat sink fault diagnosis, in order to divide the fault region of the heat sink, this paper adopts the FCM algorithm to pre-segment the transformer heat sink. FCM (Fuzzy C-Means) is an unsupervised learning method based on the theory of fuzzy sets, which is widely used in the field of image segmentation. Its core idea is to divide the image into regions with similar attributes by fuzzy classification of pixel features.

FCM breaks through the limitation that pixels can only belong to a single class in traditional hard clustering methods by introducing the affiliation function. Let the image contains  $N$  pixels, which need to be classified into  $C$  categories, and the algorithm constructs the objective function:

$$J = \sum_{i=1}^C \sum_{j=1}^N u_{ij}^m \|x_j - v_i\|^2 \quad (1)$$

Where  $u_{ij}$  denotes the affiliation of pixel  $j$  to class  $i$ ,  $v_i$  is the clustering center, and  $m$  is the fuzzy index (usually taken as 1.5-3.0). This function achieves data segmentation by minimizing the intra-class weighted distance, and the weight is the  $m$ th power of the affiliation, which enhances the classification flexibility in the overlapping region between classes.

The iterative optimization process consists of two core operations: first fixing the affiliation degree to update the clustering center:

$$v_i = \frac{\sum_{j=1}^N u_{ij}^m x_j}{\sum_{j=1}^N u_{ij}^m} \quad (2)$$

Then fix the clustering center to update the affiliation:

$$u_{ij} = \frac{1}{\sum_{k=1}^C \left( \frac{\|x_j - v_i\|}{\|x_j - v_k\|} \right)^{\frac{2}{m-1}}} \quad (3)$$

The fuzzy classification results are finally obtained by iterating repeatedly until the objective function converges.

Therefore, the implementation of FCM algorithm for image segmentation contains the following steps:

(1) Feature extraction: the gray value of each pixel, RGB color components or texture features constitute a feature vector. For two-dimensional images are often simplified to single-channel gray value processing.

(2) Parameter initialization: preset the number of categories  $C$ , randomly generated to meet the initial affiliation matrix of

$$\sum_{i=1}^C u_{ij} = 1.$$

(3) Iterative optimization: alternately calculate the clustering center and the affiliation matrix, until the change of the objective function of the two adjacent iterations is less than the threshold value.

(4) Result hardening: using the principle of maximum affiliation, each pixel is categorized into the category with the largest affiliation to form a segmentation mask.

Although the FCM algorithm can quickly segment the target region of the image, it is easy to cause edge blurring. This will affect the subsequent image analysis and processing to some extent.

### 2.2. Region Growing Method

Region Growing is a classical image segmentation method based on pixel similarity, and its core idea is to form a connected homogeneous region by gradually merging neighboring pixels with similar attributes. Different from traditional threshold segmentation or clustering algorithms, Region Growing emphasizes local continuity, starting from the seed point and expanding outward based on predefined criteria, and finally dividing the image into several internally consistent subregions with clear boundaries, which is especially suitable for scenes where the target region has uniform features and clear boundaries. In the following, a pixel  $(x_0, y_0)$  is used as the initial point to introduce its algorithmic process:

(1) Select a point  $(x_0, y_0)$  in the target object area as the initial point seed, the seed as the starting point of growth, usually selected as a typical feature point of the target area.

(2) Taking  $(x_0, y_0)$  as the center, consider 4 domain pixels  $(x, y)$  of  $(x_0, y_0)$ . If  $(x, y)$  meets the formulated growth conditions, merge  $(x_0, y_0)$  with  $(x, y)$  and press it into the heap load at the same time.

(3) Remove a pixel from the heap load, treat it as  $(x_0, y_0)$ , and return to step (2) again.

(4) When the heap load is empty, the key to the region growing method is the determination of the initial point.

From the above, it can be seen that the determination of the initial point determines the position of the segmented region in the image to a certain extent, so that different target objects get different results, while the growth rules affect the image segmentation results by establishing the merging rules for the pixels or regions within the current region or pixel field, while the termination conditions utilize the number of times the algorithm is run or the accuracy required to run the results also have a corresponding Impact. Therefore, the key to the region growing method lies in the selection of the initial point, the formulation of the growth rules and the establishment of the termination conditions, which are also the three major difficulties to be solved in the region growing method.

## 3. Flow of Transformer Heat Sink Segmentation Method Based on FCM and Area Growth Method

Aiming at the infrared thermal image of transformer heat sink, this paper adopts a new detection method, first of all, through the image preprocessing operation to get a cleaner image, to provide a basis for the subsequent fault region

segmentation; then use the FCM segmentation algorithm to pre-segment the heat sink image to remove the interference of the background, and get the target region of the transformer heat sink with a rough edge, and finally the region growth algorithm to finely divide the fault region of the heat sink to get the different fault regions of the transformer more accurately. Finally, the region growth algorithm finely divides the fault region of the heat sink, and obtains more accurate different fault regions of the transformer heat sink. The specific algorithm flow of this paper is as follows:

(1) Preprocessing electrical equipment to get a cleaner preprocessed image;

a. Using Gaussian filtering, each pixel in the image is weighted and averaged to remove the influence of noise;

b. Extract the high-frequency information using the 4-direction Laplace operator and decompose it to the bottom layer for detail enhancement.

(2) Pre-segment the transformer heat sink using the FCM segmentation algorithm to obtain a rough outline of the transformer heat sink region;

The growth region method is utilized to further finely divide the fault region of the heat sink, and the heat sink is divided into abnormal region, critical region and normal region.

The specific segmentation process is shown in Figure 1:

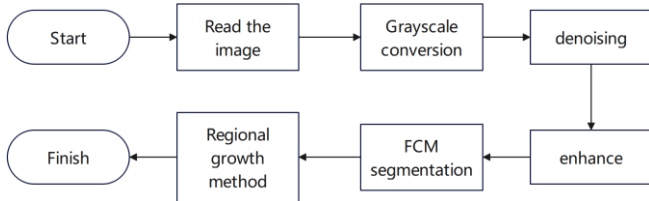


Figure 1. Segmentation Flowchart

## 4. Experimental Results and Analysis

In order to verify the practicality of the method of this paper, the experimental verification of the algorithm is carried out, and the whole experimental process is divided into two parts. The first part verifies the rationality of the fault region segmentation method in this paper, and conducts experiments according to the process; the second part verifies the superiority of the method in this paper, and compares and verifies it with the Ostu algorithm and k-means clustering method, respectively.

### 4.1. The Results and Analysis of The Detection Method in This Paper

This subsection mainly takes the infrared image of transformer heat sink as an example for verification, and Figure 2 shows the infrared image of transformer heat sink.

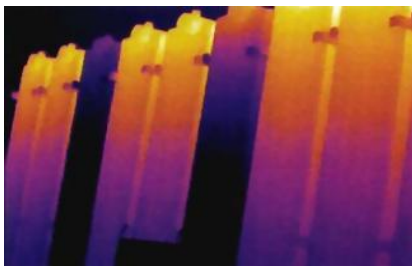


Figure 2. Transformer Heat Sink Infrared Image

(1) Denoising and enhancement of images by image preprocessing algorithms

In this paper, we first use Gaussian filtering and 4-direction

Laplace operator to denoise and enhance the image of transformer heat sink respectively. Acquired infrared images always have some noise, the subsequent fault region segmentation will have a certain impact, so the use of Gaussian filtering to complete the first image denoising, the results are shown in Figure. From the figure, we can see that after the denoising of the Gaussian filter, the image will be blurred, making the edges not obvious. So then use the 4-direction Laplace operator to extract high-frequency information, and decompose it to the bottom layer to achieve the details of the enhancement, the results are shown in Figure 3 and Figure 4. After denoising and enhancement can be obtained after a cleaner and clearer image of the heatsink, which is advantageous for the subsequent segmentation.

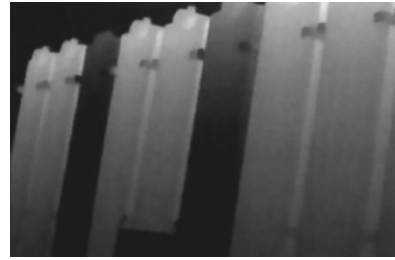


Figure 3. Gaussian filter denoising results

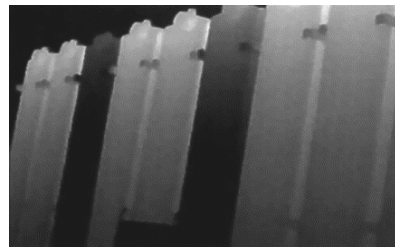


Figure 4. Laplace operator enhancement results

(2) Pre-segmentation of transformer heat sink image by FCM segmentation algorithm

After the pre-processing operation, the FCM algorithm is utilized to pre-segment the pre-processed heat sink image to extract the transformer heat sink region and remove the interference of the background, as shown in Figure 5. As the FCM algorithm belongs to the fuzzy clustering segmentation, so from the pre-segmented image species can be seen, although after roughly the heat sink region and the heat sink in the abnormal region segmented out, but the boundary between the various regions of the fuzzy, rough edges, and easy to form a small point around the target region and other phenomena, but also the subsequent completion of the size of the abnormal region of the statistics will have a negative impact on the size of the abnormal region. Therefore, the FCM algorithm can only be used as a pre-segmentation to obtain the approximate heatsink area and the approximate classification of the anomalous regions in the heatsink.

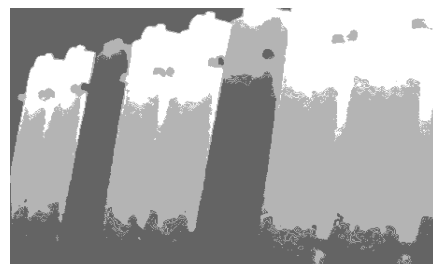


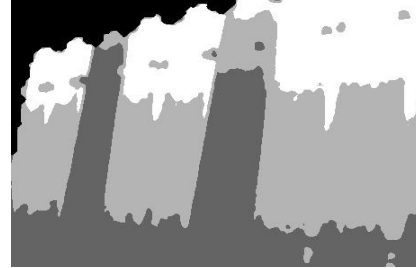
Figure 5. FCM pre-segmentation results

(3) Complementary role of region growing algorithm to

### FCM segmentation

As can be known from the previous operation step, the target region of the heat sink is obtained after pre-segmentation, and the influence of the background is removed, which facilitates the region growing algorithm to more accurately segment the anomalous region in the heat sink. Figure 6(a) shows the segmentation results after no pre-segmentation, and Figure 6(b) shows the segmentation results after image pre-segmentation. As can be seen from the figure, the segmentation without pre-segmentation using the region

growing algorithm has rough edges and cannot accurately separate the abnormal region, critical region and normal region, which may result in over-segmentation, leading to the inability to correctly analyze the operation status of each region on the heat sink; while the segmentation using the region growing algorithm after pre-segmentation can accurately delineate each region and accurately locate the faults, eliminating the interference of the different operation regions on the heat sink. The interference of different working areas on the heatsink is eliminated.



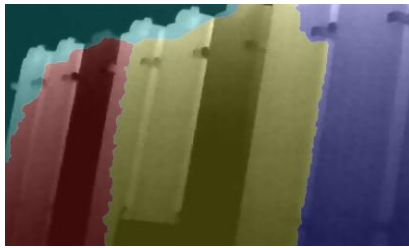
(a) Segmentation results without pre-segmentation (b) shows the segmentation results after image pre-segmentation

Figure 6. Segmentation results of region growing algorithm

## 4.2. Comparison Results of This Paper's Detection Method with Other Algorithms

Through this experiment, the algorithms such as Watershed, K-means, Threshold Segmentation, Edge Extraction, FCM

Segmentation, Region Growing Method, and Segmentation based on FCM and Region Growing Method are used, and different experimental results can be obtained when different image segmentation algorithms are used, and the results are shown in Figure 7:



(a) Watershed segmentation results



(b) K-means segmentation results



(c) Threshold segmentation results



(d) FCM image segmentation results



(e) Region growth segmentation results



(f) Segmentation results of this paper's method

Figure 7. Comparison of experimental results Fig.

Through the above experimental comparisons carried out by different algorithms, the segmentation of the heat sink using the watershed algorithm is not able to accurately segment the faulty region, and the segmentation effect is not good. The K-means and threshold segmentation can get the faulty region in the heat sink, but the segmentation is not the best, and the edge of the segmented region is more fuzzy, and

the processing is not good enough. The edge extraction algorithm is not able to realize the faulty region segmentation, and can only extract the edge part of the heat sink, and the image segmented by FCM and region growing method has over-segmentation, and part of the region is over-segmented, and at the same time, it leads to the decrease of the accuracy of the segmented region.

And the segmentation method in this paper first uses FCM to segment the pre-processed image once, although the effect of the region obtained by segmentation is not very ideal, the edge is not good enough to deal with the edge, fuzzer. But on the basis of pre-segmentation again using the region growth method for secondary segmentation, segmentation can get better three segmentation regions, in which the white region represents the normal region of the transformer heatsink, the light gray region represents the critical region of the heatsink, and the dark gray part is also the location of the black in the infrared image of the heatsink, which represents the fault region. Therefore, through the comparative experimental analysis, the scheme based on FCM and region growing method is not only able to complete the segmentation of the image quickly compared with other segmentation algorithms, but also does not have the phenomenon of over-segmentation, and at the same time, it is able to deal with the edge of the image and the background of the infrared image well, and it can realize the detection of faulty regions of the heat sink effectively.

## 5. Conclusion

In this paper, a transformer heat sink fault region segmentation method is studied, which can divide different abnormal regions of the heat sink, highlight the location of the fault region, which is conducive to more accurate maintenance of power equipment and reduces the waste of social costs and human resources. This method firstly obtains a clean image through image preprocessing operation, which provides a basis for subsequent fault region segmentation; then the FCM segmentation algorithm is used to pre-segment the heat sink image to remove the interference of the background and obtain the target region of the transformer heat sink with a rough edge, and finally the region growth algorithm finely delineates the fault region of the heat sink, which obtains a more accurate different fault regions of the transformer heat sink. region. On this basis, we will continue to carry out research on the calculation of the area of different fault areas to further realize the automation of transformer heat sink fault detection and promote the further development of unattended substation.

## Acknowledgment

Sichuan University Jinjiang College's Young Teachers' Scientific Research Fund Project (Project Number: QNJJ-2023-B06).

## References

- [1] ZHANG Qiuming, LI Yunhong, LUO Xuemin, et al. Electric equipment infrared image segmentation method based on improved Chan-Vese model [J]. *Infrared Technology*, 2023, 45(2): 129-136.
- [2] HAN S, YANG F, YANG G, et al. Electrical equipment identification in infrared images based on ROI-selected CNN method [J]. *Electric Power Systems Research*, 2020, 188: 106534.
- [3] LIU Lizhong, ZHENG Xiaocui, CHAI Weijun. Bus short circuit monitoring in low voltage disconnecter switch cabinet of distribution transformer [J]. *Electrical Automation*, 2021, 43(5): 51-54
- [4] Furse C M, Kafal M, Razzaghi R, et al. Fault diagnosis for electrical systems and power networks: A review [J]. *IEEE Sensors Journal*, 2020, 21(2): 888-906.
- [5] CHEN Tie, LYU Changqin, ZHANG Xin, et al. Transformer fault diagnosis model based on KPCA-WPA-SVM [J]. *Electrical Measurement & Instrumentation*, 2021, 58(4): 158-164.
- [6] GUO Shuangquan, HAO Huan, WANG Yang. An infrared image fault identification method for disconnecting switches based on HOG features [J]. *Infrared Technology*, 2025, 47(02):243-249.
- [7] WU Xiaojun, YU Xianche, WANG Peng, et al. Improved FCM infrared image segmentation of power equipment based on superpixel [J]. *Infrared Technology*, 2025, 47(02):235-242.
- [8] LEI Tao, JIA Xiaohong, ZHANG Yanning, et al. Significantly fast and robust fuzzy C-Means clustering algorithm based on morphological reconstruction and membership filtering [J]. *IEEE Transactions on Fuzzy Systems*, 2018, 26(5): 3027- 3041.
- [9] WANG Xiaofang, MAO Huamin. Infrared image segmentation method for power equipment in complex background [J]. *Infrared Technology*, 2019, 41(12): 1111-1116.
- [10] LI Wenpu, MAO Yingke, LIAO Xiao, et al. Intelligent diagnosis method of infrared image for substation equipment voltage type thermal defects based on rotating target detection [J]. *High Voltage Engineering*, 2021, 47(9): 3246-3253.
- [11] Deng Changzheng, Luo Bingjie, Fu Tim, et al. Infrared image segmentation algorithm for power equipment based on improved DeepLabV3+ [J/OL]. *Infrared Technology*, 1-8 [2025-03-31]. <http://kns.cnki.net/kcms/detail/53.1053.TN.20240110.1620.002.html>