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A novel intelligent fault diagnosis method for electrical equipment using infrared thermography

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HIGHLIGHTS

- Statistical characteristics are extracted using K-means algorithm.
- A coarse-to-fine parameter optimization approach of SVM is proposed.
- Seven sets of features are used as input data for the SVM classifier separately.
- The classification performance of SVM is compared with that of BP neural network.

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ABSTRACT

Infrared thermography (IRT) has taken a very important role in monitoring and inspecting thermal defects of electrical equipment without shutting down, which has important significance for the stability of power systems. It has many advantages such as non-contact detection, freedom from electromagnetic interference, safety, reliability and providing large inspection coverage. Manual analysis of infrared images for detecting defects and classifying the status of equipment may take a lot of time and efforts, and may also lead to incorrect diagnosis results. To avoid the lack of manual analysis of infrared images, many intelligent fault diagnosis methods for electrical equipment are proposed, but there are two difficulties when using these methods: one is to find the region of interest, another is to extract features which can represent the condition of electrical equipment, as it is difficult to segment infrared images due to their over-centralized distributions and low intensity contrasts, which are quite different from those in visual light images. In this paper, a new intelligent diagnosis method for classification different conditions of electrical equipment using data obtained from infrared images is presented. In the first stage of our method, an infrared image of electrical equipment is clustered using K-means algorithm, then statistical characteristics containing temperature and area information are extracted in each region. In the second stage, in order to select the salient features which can better represent the condition of electrical equipment, some or all statistical characteristics from each region are combined as input data for support vector machine (SVM) classifier. To improve the classification performance of SVM, a coarse-to-fine parameter optimization approach is adopted. The performance of SVM is compared with that of back propagation neural network. The comparison results show that our method can achieve a better performance with accuracy 97.8495%.

1. Introduction

All objects with a temperature above absolute zero emit radiation and the higher the temperature the more radiation energy. Internal and external faults of electrical equipment such as loose connection, contact problems, overload, load imbalance and improper equipment installation can produce overheating, which may lead to the failure of the equipment. Furthermore, the failure of equipment requires a lot of maintenance cost, manpower and may also cause catastrophic injures or even deaths [1]. Temperature is an important parameter for evaluating the condition of electrical equipment. Therefore, monitoring the temperature of equipment is undoubtedly one of the best predictive maintenance methodologies. Infrared thermography (IRT) is a non-contact method that measures the temperature of a body remotely and provides the thermal image which represent surface temperature distribution of the body [2]. Due to its advantages of reducing unscheduled downtime or system ultimate failure,

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increasing the proper utilization of manpower, increasing the production capacity of plants, reducing the maintenance expenditure of equipment, and increasing the life time of equipment [3], infrared thermal imaging detection technology has become a matured and widely accepted condition monitoring tool in power industry [4].

Collecting pictures by portable thermal imagers is the major form of IRT applied in electrical system for on-site diagnosis or background analysis. In [5] a transformer is divided into four parts, i.e. transformer tank, tap changer, radiator, and bushing. Temperature at upper, middle and lower spots for each part are checked and the state of each part is determined by three temperature comparatives. Most IRT cameras today have their own analysis software which have multi-functions to prepare the inspection reports and they are easy to use. However, manually fault detection and classification may take a lot of processing time and human efforts, which is even executed by a qualified or experienced technical personnel. Additionally, the analysis for a large electrical system with hundreds of equipment becomes more complicated [6]. In recent years, intelligent robot patrol technology on substation has been studied extensively and starts to have practical application. This kind of system includes visible light camera, infrared thermal imager, pickup sensor, etc. [7]. Infrared images are filmed at each docking point and transmitted to the control room for PC analysis, which can reduce the labor of manual image collections. However, the fault analysis for infrared images of electrical equipment still rely on people. Jian et al. [8] developed a substation monitoring and warning system based on infrared technology. The system collected temperature information of apparatus or each part of apparatus and compared with the normal temperatures which stored in the database. Thus the condition of the targets can be determined. There are two disadvantages in this method: one is that the normal temperature of objects will change under different condition of weather, load and so on; the other is that the system construction is expensive as it is fixed on-site.

In order to obtain a more fast and accurate diagnosis, some intelligent diagnosis systems for electrical equipment by analyzing infrared images automatically are constructed due to the rapid development in image processing techniques and artificial intelligence. They usually consist of three general steps as Fig. 1 illustrates [6]. The first step is to find the region of interest (ROI), and then the descriptive information in the regions should be extracted which can be distinctive enough to be classified in the next step. Finally, classification of the power equipment state to give the result whether this image contain a possible fault or not and how serious the fault. The key step of these intelligent diagnosis systems is to find the ROI. Incorrect or inaccurate region identification will affect the information extraction and classification process.

Huda et al. [9] proposed a semi-automatic system for thermographic inspection of electrical installation within buildings. The ROI of images were manually segmented and then statistical features were extracted which were the first order histogram, the gray level co-occurrence matrix features and the differences between hot and reference regions. Principle component analysis (PCA) was used to select the best features. Finally, 15 statistical features was used as input data for a Multi-Layer Perception (MPL) network to classify thermal conditions as normal, warning, and critical. This system achieved 78.5% accuracy. Shafi'i and Hamzah [10] developed an intelligent classification system for internal faults of electrical equipment based on infrared thermography technology. Impixelregion image processing toolbox was adopted to find the ROI manually. The RGB color data of infrared images and temperature data were used as input features of an artificial neural network. The experiment was done on 336 thermal images and achieved maximum recognition rate 99.38% in the testing phase. In [11] Zernike moments were used as image features and a support vector machine was adopted as a classifier to recognize two types of faults, i.e., the fault in the fuses cable lug and the fault in top and bottom fuse bases. The results showed 83% accuracy. An intelligent thermal imaging diagnosis system was proposed by Almeida et al. [12] for diagnosing faults in surge arresters. The system used watershed segmentation algorithm to find the region of interest and a neuro-fuzzy network to classify the thermal conditions into three classes as faulty, normal and suspicious. This system was validated using 100 thermal images and the validation error was about 10%. In another study [13], 6 features from images were selected from 15 features as a multilayered preceptron network input data and achieved 79.4% accuracy. Jaffery and Dubey [14] developed a real-time and off-line system to monitor the temperature variations and analyze hot regions in electrical assets using infrared thermography. In [15] a recursively constructed output-context fuzzy system was proposed to characterize the condition of electrical hotpots. These systems achieved 92.3% and 80% testing accuracy for classifying conditions into two and three classes, respectively.

In conclusion, there are two ways to get region of interest. In Refs. [1,11,12,14,15], the region of interest (ROI) is obtained using binary image segmentation techniques. However, the results of these segmentation methods trend to be over-segmented due to the nature of an infrared image which is quite different from that of a visual light image. The formation of a thermal image is purely based on the heat distribution of objects in this image, which brings some difficulties in image segmentation due to its over-centralized distributions and low intensity contrasts [6]. While the problem in Refs. [3,9,10,13] is that the ROI is given by manually. Obviously, this way is not conducive to reduce manual workload and accelerate the rate of diagnosis. Furthermore, it can also concluded that feature selection is researched in Refs. [1,3,9,13].

From above we can see that the difficulties of intelligent fault diagnosis for electrical equipment based on infrared images are to find the accurate ROI and extract features which can characterize the equipment conditions. In this paper a new intelligent diagnosis system is proposed in order to overcome these difficulties. In the first stage of our method, an infrared image is clustered into k (k is the cluster number) regions using K-means algorithm. Then statistical characteristics (i.e., temperature and area information) are extracted in each region. Finally, seven sets of features which are combined by some or all statistical characteristics from each region are used as input data for a SVM classifier. To reinforce its classification performance, a parameter optimization approach is presented. The main contributions of this paper are twofold: First, statistical characteristics are extracted using K-means algorithm to avoid the difficulties in finding the accurate ROI, and some of these features (e.g., temperature information without mean or median values when infrared images are clustered into 3 regions) can well characterize the electrical equipment conditions; Second, a coarse-to-fine parameter optimization approach is proposed to improve the performance of SVM.

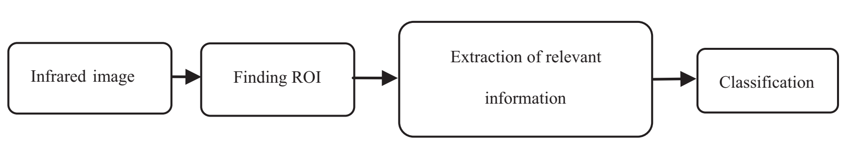

Fig. 1. General steps of an intelligent diagnosis system.