THERMAL ENERGY DIAGNOSIS OF BOILER PLANT BY COMPUTER IMAGE PROCESSING AND NEURAL NETWORK TECHNOLOGY

by

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Original scientific paper
https://doi.org/10.2298/TSCI191218128Y

The paper aims to study the identification and diagnosis of infrared thermal fault of airborne circuit board of equipment, expand the application of intelligent algorithm in infrared thermal fault diagnosis, and promote the development of computer image processing technology and neural network technology in the field of thermal diagnosis. Taking the airborne circuit board in the boiler plant as the research object, first, the sequential analysis method was selected to collect the temperature changes during the operation of the circuit board. Second, on the basis of convolutional neural network, the program was written in Python, and the Relu function was used as the activation function establish the thermal fault diagnosis method of the on-board circuit board of the boiler plant equipment based on the convolutional neural network model. Third, based on the support vector machine intelligent algorithm, genetic algorithm was used to optimize the parameters, and combined with the grey prediction model, the infrared thermal fault diagnosis scheme of the circuit board of the multistage support vector machine boiler plant equipment was constructed. The results showed that the accuracy of the model after 6000 iterations was stable between 0.92-0.96, and the loss function value was stable at about 0.17. After the optimization of genetic algorithm, the accuracy of thermal fault diagnosis based on support vector machine model was optimized. Compared with grey prediction model, the accuracy of support vector machine model for fault diagnosis was higher, mean square error value was 0.0258, and the correlation coefficient was 91.55%. To sum up, the support vector machin model shows higher accuracy than grey prediction model, which can be used for thermal fault diagnosis.

Key words: *support vector machine, infrared thermal fault, sequence analysis, convolutional neural network, boiler plant equipment*

Introduction

In recent years, with the rapid development of computer information technology, image data plays a more and more important role in the production and life. Hence, the development of computer vision technology which uses computer to process image is emphasized [1, 2]. Computer image processing technology, also known as image processing technology, uses computer tools to analyze and process images. Its main contents include image compression, enhancement, and restoration, as well as image matching, description, and recognition.

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The common processing methods include image coding, image enhancement, image digitization, image restoration, image segmentation, and image analysis. Different from the visual recognition, the recognition and reading of image in computer vision technology is completed by using various visual devices to convert the perceptual image into discrete pixels and form a matrix. Meanwhile, the computer cannot understand all the information contained in the image. Based on this, using deep learning to extract image features has become a hot research direction [3-5]. The emerging neural network technology can simulate the interaction between the biological neural system and the real world, and has achieved some research results in the fields of artificial intelligence and pattern recognition. At present, neural network is applied to image processing to achieve the continuous research on image feature extraction and image semantic analysis [6].

Infrared technology applies infrared radiation engineering research projects. It mainly studies the whole process of the generation, transmission, and reception of infrared radiation [7, 8]. Infrared detection technology is used to detect the infrared radiation intensity, and then converts it into quantitative temperature data, and applies the effective computer big data technology to realize the mining and detection of potential information [9, 10]. The wavelength range of infrared is about 10 times that of visible light, the wavelength range of infrared is 0.75-1000 μm, and the wavelength range of visible light is 0.38-0.75 μm. Thus, the infrared emitted by an object contains more and more detailed information than visible light, and the performance of an object can be better detected from the perspective of infrared radiation. In the application of infrared detection technology, the most widely used detection equipment is infrared thermal imager. With the help of photoelectric effect, thermal effect, and other principles, the detection equipment realizes the process of converting infrared radiation into electrical signal which is easy to measure, and converts the collected radiation intensity into corresponding infrared thermal image. At present, infrared detection technology has been applied in many fields, such as fault diagnosis and non-destructive testing. After collecting the infrared thermal image, the infrared thermal imager presents it in pseudo color image aided by computer. When an object has a fault or is damaged, the change of its infrared radiation can be clearly seen in the infrared heat map. The fault reason and damage type can be found by establishing the infrared temperature model according to the different fault or damage conditions. The infrared detection technology can complete the non-destructive testing without contacting the production equipment, and find the fault. In the process of equipment operation, infrared detection technology can complete the real-time detection of abnormal heating, so diagnosis and maintenance can be carried out as early as possible. In the process of equipment operation, the boiler plant will also cause thermal radiation and short circuit fault of electric heating plate, while the infrared thermal imager can detect the circuit board in the equipment on the premise that the equipment continues to operate. Compared with the traditional detection method, it has significant advantages, which is necessary to further explore [11, 12].

Starting from the thermal diagnosis of the airborne circuit board of the boiler plant equipment, this paper initially establishes the infrared thermal fault diagnosis (TFD) method of the electric heating board based on the sequence analysis method. In addition, the infrared TFD scheme of the circuit board is proposed based on convolutional neural network (CNN) combined with Python language and Relu activation function. Moreover, the infrared TFD scheme of the circuit board based on support vector machine (SVM) is constructed through parameter optimization, to provide some reference for the application and development of computer image processing and neural network technology in thermal diagnosis.

Methods

Sequence analysis

The sequence analysis method, for the analysis and detection of equipment fault diagnosis, collects the temperature sequence of the normal and stable operation of the equipment, puts each temperature value collected into the database as a sample, and establishes a standard data sample database, thus completing the diagnosis and detection of the fault [13]. This method is applied to the fault identification and analysis of the airborne circuit board of the boiler plant equipment. The specific operation is: collect all the temperature values of the airborne circuit board from power on normal operation, show the temperature change in temperature rise curve on the time axis, collect the temperature rise data for many times, and establish the corresponding standard data sample library. Collecting the change data of all the temperature series aims to prevent the fault missed diagnosis and judgment caused by single time sampling, and to eliminate the accidental problems in the data collection.

The convolutional neural network

The CNN is developed based on neural network, which is mainly composed of input layer, convolution layer, pooling layer, slice layer, fusion layer, full-connection layer, and activation function, and each layer has specific functions [14]. The infrared TFD algorithm based on CNN consists of three parts: input layer, invisible layer, and output layer. In the input layer, all the input data information will be integrated into a 1-D vector, in which the initial structure of the input image and data can be preserved; in CNN, the convolution layer is the vital component, which can realize the feature extraction of the image. The pooling layer mainly samples the features extracted in the convolution layer, which can reduce the dimension of the feature value and prevent over fitting. The Relu function is the main activation function used in CNN. The slice layer is used to cut the image, and to learn a certain independent area separately. The fusion layer is used to fuse the feature information learned from the sliced image or convolution kernel. The full-connection layer is mainly used to re-fit the extracted feature, which can reduce the lack of extracted feature information. In CNN, the convolution kernel is calculated and the Relu activation function is shown:

$$c(x,\mathrm{y}) = z(x,y)\,g(x,y) = m\sum z(x-m,y-n)\,g(m,n) \tag{1}$$

where z is the input data corresponding to the 2-D image, g – the convolution kernel, and (m, n) – the indicates the size of the convolution kernel:

$$f(y) = \max(0,y) \tag{2}$$

The SVM intelligent algorithm

The SVM algorithm, originated from statistical learning theory, is an intelligent machine learning (ML) algorithm with very good generalization, which has been widely used in system classification, regression analysis, system state recognition, and other related fields [15]. The SVM algorithm has excellent performance and strong generalization ability. When facing the high-dimensional sample data, it will not make the calculation process complex. It has significant advantages in ML problems related to small samples. For the small sample problem, it has a unique theoretical system, which can achieve the effect of minimizing the upper bound of generalized error under the condition of minimizing structural risk. The kernel function is introduced to realize the mapping from the collected data to the high dimension. The linear clas-

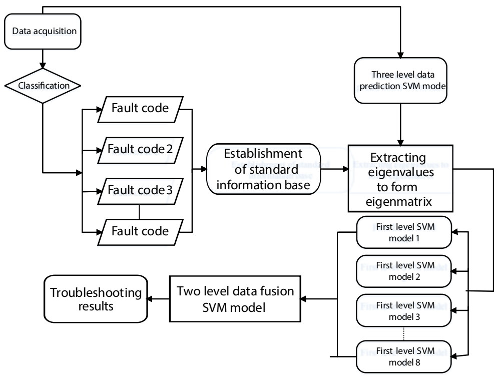

Figure 1. Multi-level SVM TFD and prediction algorithm

sification problem that cannot be completed in the low dimension space can be transformed into the solution in the high dimension feature space. Thus, it can achieve the distinction between the fault of the circuit board used in the boiler plant equipment and complete the classification between the normal and fault problems. The optimization of the optimal hyperplane of SVM is shown in eq. (3), and the corresponding algorithm flow chart of multi-level SVM TFD and prediction is shown in fig. 1:

$$\sum_{i=0}^{m} \omega_i \zeta_i (T) + b = 0 \tag{3}$$

where ω_i is the weight connecting the characteristic space and the output, b – the bias, and T – the stable working temperature of the circuit board device in the boiler plant equipment.

Results and discussion

Infrared thermography fault diagnosis by sequence analysis

In the establishment of the infrared thermal fault system for the airborne circuit board of the boiler plant equipment, the infrared thermal imager is the core component of the complete detection system. The sequence analysis method is selected to collect the temperature sequence of the airborne circuit of the equipment in the boiler plant in the normal operation time stage, and the temperature value of every 1 second during the heating process of the circuit board. Taking this as the database sample, the curve between the normal circuit board and the circuit board to be tested is fitted. Figure 2 shows the change of the data fitted.

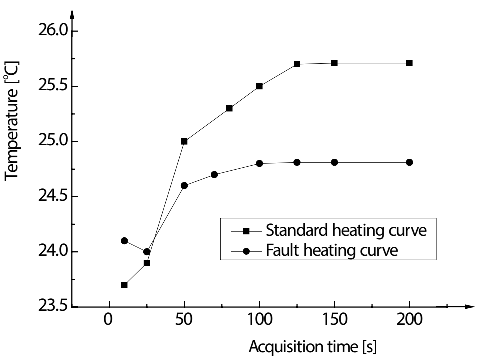

Figure 2. Sequence analysis of airborne circuit board

Figure 2 shows that when the airborne circuit board of the equipment works normally, the fitting curve corresponding to the circuit board to be tested is very close to that in the standard database. While in contrast, when the airborne circuit board of the equipment is in fault, the matching rate between the fitting curve of the circuit board to be tested and the fitting curve in the standard database is very low. Thus, the fault condition of airborne circuit board can be judged.

The sequence analysis method can be used to transform the thermal fault information into time series, which transforms the fault diagnosis to the data analysis. The sequence analysis method has strong practicability, and can analyze and detect the infrared thermal radiation fault. However, in the application of sequence analysis, it is necessary to collect data every second in the working state of airborne circuit board, which involves too much data information, so it will make the analysis of thermal fault complex. In addition, the huge amount of data must also contain some interference analysis data. The mixture of fault information and interference information will lead to errors in the thermal fault analysis of airborne circuit board, resulting in wrong judgment. In view of the shortcomings of the sequence analysis method, for all the temperature data information, it needs to establish a method to extract the characteristic parameters for realizing the fault information mining. Therefore, it is essential to seek other solutions to realize the fault diagnosis and prediction of the airborne circuit board of the boiler plant equipment, which needs to be concerned and focused on.

Infrared thermal fault identification based on CNN

Tensor flow is a kind of deep learning development framework with simple code, convenient deployment, and good balance. Linux_x86 operating system is selected to complete the construction of CNN. The 64 × 64 parameter input is used to preprocess the pictures in the training set, write programs in Python programming language, and use Relu function as the activation function complete the construction of CNN model. In the model training, the training accuracy is output once every 200 times, and the corresponding model training process is shown in fig. 3.

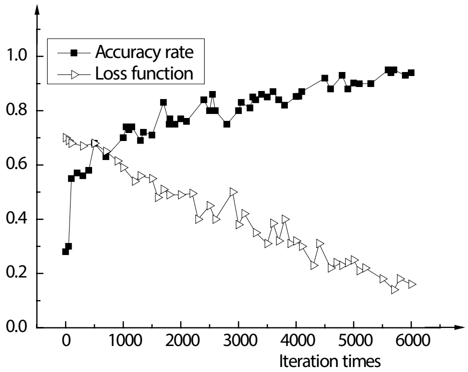

Figure 3. Training results of CNN model

The training process of CNN model suggests that after 6000 iterations, the accuracy of the model has been stable between 0.92-0.96, and the corresponding loss function is basically stable around 0.17. The fault model based on CNN can realize the classification and recognition of thermal fault of circuit board in boiler plant equipment.

At present, CNN is one of the most important methods in image recognition and classification. Compared with the traditional algorithm, CNN is based on the learning method. Through the training, even for the objects with high surface similarity, it can achieve accurate classification and recognition. Moreover, the migration characteristics of CNN can replace the last layer of the trained CNN, thus identifying other similar objects through training. In the identification of the thermal fault of the circuit board in the boiler plant equipment, the traditional algorithm marks the location of each circuit board in the equipment that may produce the thermal fault by selecting the marking method, and then uses the prepared template to match in the actual diagnosis process. This method is not only cumbersome to implement, but also difficult to achieve accurate matching with the template. The CNN is applied to the infrared TFD and prediction of the circuit board of the boiler plant equipment. The network composed of many neurons is connected with each other. After collecting the temperature information of the normal working state and fault state of the airborne circuit board, the training set is formed according to the causes of the fault. Through the combination of forward learning and back propagation, the result of training neural network model is achieved. The collected temperature data is input into the corresponding input layer neurons, and then through the propagation of network weights to the hidden layer and output layer for establishing the relationship between the input information and output information and outputting the fault devices and corresponding fault causes.

Infrared TFD of multistage SVM

According to different eigenvalue attributes, the infrared TFD model of the circuit board of the SVM boiler plant equipment is constructed, and then the SVM model of data fusion is established to form a higher-level infrared TFD model of the electric heating board of the

SVM boiler plant equipment. The temperature value of the circuit board is returned to the TFD model of all levels of SVM in turn, and the extracted feature sample data is trained by using the standard information base. Additionally, the linear indivisible problem is decided by the optimal hyperplane, then the penalty coefficient, p, and kernel function coefficient, k, of the SVM model are optimized by using genetiic algorithm (GA). Based on the multi-level SVM algorithm model, the TFD method of electric heating plate in boiler plant is established. Finally, the thermal fault is predicted by grey prediction, and the error level is measured by mean square error (MSE). The changes in the optimization process of the corresponding GA are shown in fig. 4. Based on the grey prediction, the thermal failure prediction of the electric heating plate of the boiler plant equipment is shown in fig. 5. The thermal failure prediction results based on the SVM model are shown in fig. 6.

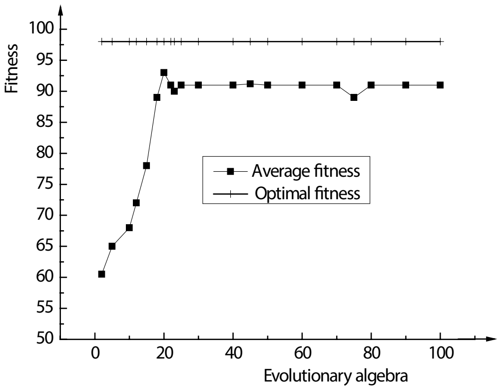

Figure 4. Parameter optimization based on GA

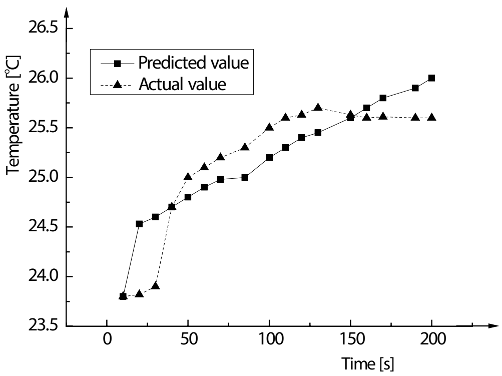

Figure 5. Comparison between actual value and predicted value under grey prediction model

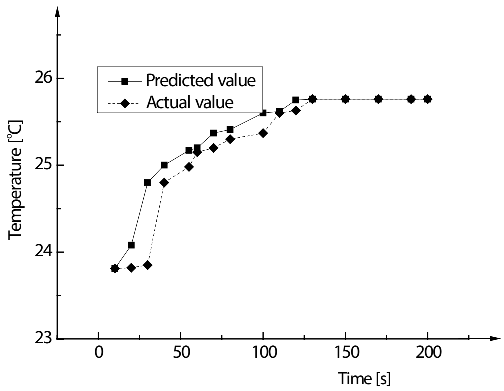

Figure 6. Thermal fault prediction results of circuit board based on SVM model

The data shows that after the optimization of GA, the penalty coefficient, p, in SVM model changes to 24.083, and the kernel function coefficient, k, changes to 19.709, so the accuracy of TFD reaches the optimization state. By measuring the average error level of SVM model by MSE, the error produced by the grey prediction model is not large, and the corresponding MSE value is 0.0695. The temperature in the prediction shows a rise first, and continues to maintain a linear rise after passing through the inflection point, which is not in line with the actual situation, so the prediction of infrared thermal fault is not well realized. In contrast, the MSE between the actual value and the predicted value is 0.0258, the correlation coefficient is 91.55%, and the accuracy of thermal fault prediction is higher.

The GA optimizes the parameters by evolving the selected sample population the optimization. It only preserves the parts with high adaptability in the population, and then continues to complete the evolution, while generating new individuals through mutation and hybridization. Hence, it improves the accuracy of the TFD model based on multi-level SVM algorithm.

The grey prediction theory defines the random process accompanying the state change as the grey process changing in the time domain. It relies on the transformation of grey quantity to find the change rule in the time series, and then realizes the mining of information and the prediction of unknown data. However, the change of temperature is complex, high-dimensional, and non-linear, which makes the grey prediction model difficult to predict the infrared thermal fault. The TFD and prediction method based on SVM model takes the collected temperature as the research object and does not need to establish complex mathematical model. This multi-level SVM model-based TFD has high accuracy and is consistent with the actual trend of change. It is expected to play a role in the prediction of the aging degree and service life of the circuit board of the boiler plant equipment.

Conclusions

Based on the thermal energy diagnosis of the airborne circuit board of the boiler plant, this paper studies the application of computer image processing and neural network technology in it. According to the sequence analysis method, a preliminary diagnosis scheme for the infrared thermal fault of the airborne circuit board of the boiler plant is established. The scheme of infrared TFD for airborne circuit board based on CNN is established. Based on the SVM intelligent algorithm and the parameters optimized by GA, the infrared TFD scheme of multi-level SVM airborne circuit board is put forward.

Through analysis and observation, it is found that the sequence analysis method has strong practicability and can analyze and detect the infrared thermal radiation fault, but the amount of data information involved is too large, which will lead to errors in the thermal fault analysis of the airborne circuit board. In the infrared TFD of airborne circuit board based on CNN, after a certain number of iterations, the accuracy and loss function value of the model are stable in a proper range, which can realize the classification and identification of thermal fault of circuit board in boiler plant equipment. In the multi-level SVM fault diagnosis, the parameter optimization of GA improves the accuracy of fault diagnosis, and the SVM model shows a higher accuracy than the grey prediction model, which is expected to play a positive role in predicting the aging and service life of the circuit board of the boiler plant equipment.

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Paper submitted: December 18, 2019
Paper revised: January 21, 2020
Paper accepted: February 8, 2020