Gas sensor fault diagnosis based on Convolutional Neural Network

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Abstract. Gas sensor often fails due to the influence of temperature, humidity, lighting, dust and toxic gases, and causes unreliable phenomena. Therefore, the fault diagnosis of gas sensors is considered as a weak link. Feature extraction and classification play an important role in gas sensor fault diagnosis. However, there are many problems in traditional feature extraction methods. For example, 1) requirements for expert experience, 2) sensitivity of changes in mechanical systems, 3) limitations of new feature extraction. Therefore, it is meaningful and attractive to develop a method that can discover and learn fault-sensitive features of gas sensors from the original data and classify them effectively according to the sensitive features. Convolutional neural network(CNN) has been widely applied in image analysis and voice recording, and has achieved great success. However, gas sensor fault diagnosis is rarely applied. This paper focuses on using CNN to learn fault features from data, extract features automatically, and then classify them effectively. Experiments show that the CNN method provides a effective solution for gas sensor fault diagnosis.

1. Introduction

Gas sensor used in coal mine safety detection, food inspection, air environment monitoring, gas energy monitoring, etc[1,2,3,4].However, because chemical sensors are vulnerable to poisoning, oxidation and other chemical characteristics of their own, as well as in the actual monitoring work, because the environment is complex and changeable, and more harsh, at the same time affected by temperature, humidity, lighting, dust and toxic gases, these factors are very likely to lead to gas sensor fault[1]. How to detect the faults of gas sensor has become an urgent and challenging research topic[5,6,7,8].

Therefore, for the fault diagnosis of gas sensor, many scholars have done relevant research, because the signal of gas sensor fault is non-stationary and non-linear, at present, most scholars use supervised learning to extract features. For example, Short-time Fourier transform(STFT), Wavelet Transform, empirical mode decomposition(EMD)[9], ensemble empirical mode
decomposition (EEMD) and so on [5]. These methods can extract features to a certain extent, but there are some drawbacks, these methods require abundant domain expertise and prior knowledge for feature extraction. More importantly, sensor fault features are sensitive to change. The change of fault conditions will affect features extraction method and evaluation criteria. Therefore, it is of great practical significance to develop an automatic learning feature method.

CNN is considered as one of the most effective methods in deep learning, CNN has the advantage of not relying on experts for feature extraction [10], and it is widely used in image classification. It has been reported that one-dimensional CNN has been used for real-time motor fault diagnosis [11]. Guo et al. applied deep CNN for bearing fault diagnosis [12].

In our paper, the new fault diagnosis method of gas sensor relied on CNN has been proposed, the feature extraction could not been intervened by human. The validity of the method is verified by the designed experimental system. Compared with other algorithms, the effect of CNN method is remarkable.

The paper has been organized as follows. Following the introduction, in Section II, theoretical background of CNN has been introduced briefly. In Section III, CNN method for gas sensor fault diagnosis has been proposed. In Section IV, description of the experimental process and results in detail. Finally, the conclusion is presented in Section V.

2. Background knowledge of CNN

CNN is one of the most effective methods in deep learning, which is inspired by visual perception mechanism. It has been applied for more than 20 years in classification in image and speech [13]. At present, the pattern recognition system based on CNN is one of the best performance systems [14].

In this study, CNN is used to solve the fault diagnosis of gas sensors. Figure 1 illustrates the architecture of LeNet-5.

![Figure 1. Architecture of LeNet-5](image_url)

3. CNN method for gas sensor fault diagnosis

In our research, firstly, the fault data of gas sensor is transformed into two-dimensional image form, and then the fault image of sensor is input to CNN for fault diagnosis. Parameters of CNN during training settings are shown in Table 1. Among them, the classification of softmax layer is set to four types, the number of iterations calculated by CNN is 500, the high of the input picture is 40 pixels, the width is 50 pixels, the batch size is set to 20, the capacity is 50, and the max step is 500.

| Table 1. Parameters of CNN during training |
|-------------------------------------------|
| Parameters name | Parameters value |
|-----------------|------------------|
| Softmax         | 4                |
| Iteration       | 500              |
| Img_h           | 40               |
| Img_w           | 50               |
| Batch size      | 20               |
| Capacity        | 50               |
| Max step        | 500              |
4. Experiment and results

4.1. Experimental setup

The sensor fault data set in this paper is obtained from the gas sensor array system designed by us. The experimental system consists of data acquisition card, mass flow controller, gas chamber, computer, a gas source of hydrogen and sensor array, as shown in Figure 2. Hydrogen is injected into the gas chamber in the form of gas and detected by the sensor array. The detection signal is picked up by the data acquisition card and then transmitted to the computer.

![System diagram of gas sensor arrays.](image)

4.2. Data description

According to the practical experience and experiment, the main fault modes of gas sensor can be determined as follows: cyclic fault, impact fault, bias fault and drift fault. Each fault type is caused by the corresponding cause. But it is difficult to get the fault signals, so we use MATLAB to simulate four kinds of fault signals. For each fault mode, we use 500 groups of samples as training data and 50 groups of samples as test data.

4.3. Results

The fault diagnosis results have been described in table 2. Compared with the other two fault diagnosis methods, the method for CNN fault diagnosis has higher diagnosis accuracy, which is 7.04% and 10.5% higher than the other two methods respectively.

| Methods                  | Accuracy (%) |
|--------------------------|--------------|
| EMD + energy features + SVM | 92.87%       |
| EMD+SVD+SVM              | 89.41%       |
| CNN                      | 99.91%       |

5. Conclusion

In this paper, the main contributions are designing a circuit board for gas sensor fault diagnosis, proposing a CNN relied on LeNet-5 method which provides the ability of automatic feature extraction, and applying the models to the gas sensor fault diagnosis with the ability of processing raw data as input and diagnostic results as output. Its main advantage is that it is suitable for the fault diagnosis of gas sensors in practice where an accurate mathematical model is unavailable, too complex. It has the ability of learning to extract the optimal features through appropriate training. This not only achieves a high degree of generalization, but also avoids the need of manual feature extraction. At the same time, the classification effect of this method has a good scalability, and it also has a good application effect in the dimension classification of economic crime abnormal funds detection. Experimental results demonstrated that the learned features are meaningful, recognizes fault type effectively, and compared to manual feature extraction, the new proposed method mentioned in our paper has yielded an improvement in classification accuracy. The actual experiments illustrate the effectiveness of CNN method for sensor arrays fault diagnosis in engineering applications.
6. Acknowledgments
This work was supported by the External Training Program for High Level Innovation Teams from 2018 to 2019 of the Department of Education of Liaoning province(Grant: 2018LNGXGJWPY-YB033), Youth Project of the Educational Department of Liaoning Province (Grant:LQ201763003) and the Project of Collaborative innovation center of economic crime investigation and prevention and control technology of Jiangxi Province (Grant: JXJZXTCX-028)

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