Research Status and Trend of Fault Diagnosis Based on Deep Belief Network

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Abstract. Modern industrial systems are moving towards large-scale, complex, and high-speed. It is difficult to solve a series of technical problems that rely on traditional fault feature extraction methods. Since the concept of deep learning has been proposed, it has shown obvious advantages in many aspects. It includes feature extraction and pattern recognition. Therefore, many scholars have conducted deep learning to solve the problems of complex industrial system fault diagnosis. The deep belief network is the typical deep learning technologies in the field of control. This paper mainly introduces the deep belief network and describes its main ideas and methods. Finally, the paper summarizes the problems faced by the current deep belief network in the area of fault diagnosis and the future research direction.

1. Introduction

Nowadays, computers, sensors and communication technologies are constantly evolving, the scale and complexity of modern industrial machinery and equipment continue to increase. These complex large industrial systems have generated massive data. The data reflect the process operation mechanism and the operation state. And it presents the obvious characteristics of integrity, openness, dynamics and emergence [1]. So, it is no longer possible to completely rely on the traditional data-driven fault diagnosis method for monitoring and management. Therefore, the manufacturing industry cannot achieve a big leap without the support of cloud computing, big data, artificial intelligence and other technologies. The equipment fault diagnosis and maintenance urgently need the support of intelligent sensor network, intelligent diagnosis algorithm and intelligent decision-making system, expert diagnosis platform and remote diagnosis technology [2-3].

In general, a fault is defined as an unallowable deviation in at least one system feature or variable. Fault diagnosis technology mainly monitors the state of the system, diagnoses faults, completes fault detection, separation and prediction [4]. Throughout the process of development of fault diagnosis technology, there are several different diagnostic methods in fault diagnosis technology [2]: methods based on analysis model, qualitative empirical knowledge and data-driven methods. The method based on the analytical model is the mathematical model of the system and the earliest and most systematic diagnostic method. Diagnostic method based on qualitative empirical knowledge is developed by means of testing technology. It analyses measurable signals through signal model, extracts characteristic values and obtains signs related to faults. At present, the data-driven diagnosis method is the main research direction of fault diagnosis. The problem of multi-symptom and multi-fault in large complex systems can be solved.
Deep learning is growing rapidly in academia and industry. It has been widely used in academic and industrial circles. And it has significantly improved the recognition accuracy in many traditional recognition tasks. It demonstrated its superb ability to handle complex recognition tasks, and attract a large number of experts and scholars to carry out research on its theory and application [5].

2. Fault Diagnosis Based on Deep Belief Network

2.1. Research Status of Fault Diagnosis Based on DBN
Tamilselvan P et al. [6] proposed a multi-sensor fault diagnosis method based on DBN (deep belief network). And they applied it to aircraft starter and electric force transformer for the first time. They realized the classification of sensor health status characteristics, and promoted the attention in this field. Since then, more and more scholars have studied the field of DBN and fault diagnosis and achieved many research results. Tran V T et al. [7] studied the vibration signal with transient impact and complex background noise, excavated the fault mode hidden in the signal, and obtained higher fault identification rate in the reciprocating compressor valve fault diagnosis. Shao H et al. [8] integrated the DBN algorithm with other algorithms and obtained relatively good recognition accuracy in the absence of prior fault information of swivel bearing. Li C et al. [9] followed up the previous studies and continued to carry out research in such fields as anomaly detection and recognition of gear box depth fault feature extraction and recognition based on DBN. They achieved incomparable effects and advantages over traditional methods and verified the robustness and accuracy of their methods. Jia F et al. [10] directly extracted and identified fault features of the rotary bearing from the frequency domain and got great performance.

In recent years, more and more studies have been conducted on the application of deep belief network in the file, from sensor health diagnosis [6] to compressor gearbox [9] rolling bearing [8,10].

2.2. Overview of Deep Learning
The concept of deep learning stems from the study of artificial neural networks. Multi-layer perceptron with multiple hidden layers is the significant feature of deep learning model, and it can simulate the neural structure of human brain. Widely used in the field of control, the basic model framework of deep learning including Deep Belief Network (DBN) [11-12], Stacked Autoencoder (SAE) based on Autoencoder (AE) [13], Convolutional Neural Network (CNN) [14] and Recurrent Neural Network (RNN) [15].

The essence of fault judgment in fault diagnosis technology is pattern recognition. After nearly ten years of development, deep learning has many incomparable advantages over other network learning algorithms with its powerful automatic feature extraction capability [16]. Compared with general neural networks and machine learning models, deep learning can solve complex problems more accurately and efficiently [17]. Deep belief network as one of the representative algorithms of the technologies, it has been applied more and more in fault diagnosis. This chapter mainly expounds the main idea and method of fault diagnosis based on deep belief network.

2.3. The Method of Fault Diagnosis
DBN can discover the distributed characteristics of data by combining the underlying features to form a more abstract high-level representation. The motivation is to build models that mimic the neural network connections of the human brain. It distributes representation of input data through multi-layer perceptron of hidden layers of multiple nonlinear operations. And it can realize the essential characteristics of learning data set under the condition of limited sample set, so as to realize the feature representation and extraction of measured data from low level to high level [18].

DBN is developed based on artificial neural network and consists of two parts: dominant neurons for receiving input data and recessive neurons for high-level feature extraction. The key component of the DBN is the restricted Boltzmann machine (RBM), which detects, identifies and classifies the input data by combining multiple layers of RBM with the final classifier [19]. Its powerful ability to implement feature extraction is that unsupervised layer-by-layer training can learn some nonlinear complex functions by directly mapping data from input to output [20].
As the cornerstone of DBN model, each RBM layer communicates with its front and rear layers, and no horizontal communication occurs between nodes in a single layer. The deep belief network optimizes the connection weight and threshold of the deep confidence network layer by layer through the unsupervised greedy learning algorithm. It can be seen as the stack of multiple RBM. By stacking multiple RBM, the characteristics of the deep layer can be extracted from the complex data [21].

On the basis of analysing the basic principles of deep belief network, combining the limitations of current fault diagnosis methods and the advantages of deep belief network, a fault diagnosis method of DBN is summarized [20]. There are five main steps:

1) Define fault types. The time domain monitoring signals of complex equipment in different health states are obtained by using sensors.
2) The fault signal and equipment state are coded and normalized separately.
3) Label the original information data set as training set and test set.
4) Initialize DBN network parameters, adjust the number of hidden units in each layer, train RBM network layer by layer, fine tune network parameters, and obtain the optimal weight matrix information.
5) Test the network through test sets.

From the above steps, the main differences between DBN method and other methods in fault diagnosis are as follows. The fault feature extraction and classifier of DBN method are integrated together and the method have certain universality. In this paper, DBN input is the original data, does not need to go through complex signal processing operations, and it will not be affected by human factors, resulting in the degradation of recognition performance. DBN method is a multi-layer model, compared with the traditional shallow diagnosis method, it can effectively avoid dimensional disaster and insufficient diagnostic ability and other problems.
2.4. The Method of Feature Extraction

Feature extraction is the important step of intelligent fault diagnosis method. The feature extraction of complex equipment fault signal determines the effect of final fault diagnosis, and thus affects the final prediction and maintenance [22].

Since the deep belief network was first proposed in 2006 [23], they proved that it has a strong feature extraction ability. In the following decades, more applications have proved its feature extraction ability [17].

Deep belief network is a self-learning feature extraction algorithm. It is widely used in a large number of fields due to its strong feature extraction ability and the fact that it does not require multiple sets of tag data. The process of extracting fault features by DBN is shown in figure 1. Firstly, unsupervised DBN model is trained layer by layer, then the DBN model is supervised by the reverse fine-tuning algorithm. Finally, the data set to be tested is input into the trained DBN model, and the output vector of each hidden layer are recorded. The steps of fault feature extraction are shown in table 1.

Table 1. DBN fault feature extraction process.

| Steps | Content |
|-------|---------|
| 1     | Define fault types |
| 2     | The various types of signals are individually normalized [0,1] |
| 3     | Divide the data set |
| 4     | Initializes the parameters associated with the DBN |
| 5     | Train the stacked RBM with the training set |
| 6     | Enter the test set into the trained stacked RBM model. Record the output vector of each hidden layer |

2.5. The Simulation Case

Zhao G Q et al. [20] verified the effectiveness of the deep belief network algorithm in fault identification through experimental data. They extracted features layer by layer from the original signal according to the steps described in table 1, and extracted the first two principal components of these features by PCA (principal components analysis) method for visualization. Figure 3 is a visualization diagram of the original features of the simulation signal [20].

Figure 3. Simulation data set visualization of the original features [20].

Figure 4. Simulation data set visualization of feature extraction by DBN method [20].
As can be seen from figure 3, the features of the three types of simulation signals overlap and are hard to be distinguished from each other. Figure 4 show the visualization diagram after feature extraction of simulation signals by DBN method.

As can be seen from figure 4, the simulation signals of the same category are effectively clustered together, and the simulation signals of different categories are well separated. It can be concluded from the comparison between the results in figure 3 and figure 4 that the DBN model has the ability to automatically extract fault features. And it can identify faults directly from the original time domain signals. It can not only achieve better recognition accuracy, but also simplify the feature extraction process in traditional fault diagnosis methods.

3. Conclusion
At present, DBN has great potential in the field of fault diagnosis, and further research is increasing, but the research is still not mature, there are still many problems to be solved, the main problems are summarized as follows:

1) Only taking DBN as a classifier, traditional signal processing method is still used to extract fault features, but the ability of mining fault features by DBN is not fully utilized.

2) When using DBN algorithm to extract fault features and identify health status of collected fault signals, frequency domain signals are mostly used. When the signals are not periodic, this method will fail without generality.

3) The comparison between DBN and other shallow models is not sufficient.

In the future, how to use deep learning method to effectively fault diagnose complex systems from multi-source heterogeneous sensor data is a direction that needs further research in the future.

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