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Case Study Analysis of Equipment Fault Diagnosis for Course of Mechanical Measurement Technology

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Abstract: The course of mechanical testing technology occupies a very important position in the mechanical major, and signal processing technology is its main teaching content. This paper introduces a fault diagnosis case based on vibration sensor to deepen students' understanding of signal processing process. Taking a certain mechanical equipment as the research object, a vibration sensor is arranged to monitor the vibration of the equipment during operation. Then, the vibration data of the equipment under different working conditions are collected and analyzed. Based on the feature extraction of vibration data in time and frequency domain, principal component analysis is used as the feature selection method. Finally, the fault analysis is carried out with support vector machine. Through this case, the students could better understand how to use vibration data for fault diagnosis analysis.

1. Introduction

Signal analysis and processing is an important part of the course of mechanical testing technology. It also has important applications in industrial equipment fault diagnosis. With the continuous development and application of industrial automation technology, various equipment and systems play a vital role in the production process. However, in the long-term operation of various engineering systems, there will be a variety of failures, due to equipment aging, operating conditions, changes in the external environment and other reasons. Therefore, the fault diagnosis of mechanical equipment plays a vital role in engineering applications. Timely and accurate fault diagnosis is crucial for maintaining production safety, improving equipment reliability and reducing maintenance costs.

Common fault identification methods usually analyze vibration signals containing fault information to detect faults, which can be divided into three categories: model-based methods [1], knowledge-based methods and data-based methods [2-3]. Model-based methods require the establishment of accurate mathematical models for the object of study. However, the mathematical model of nonlinear system is often difficult to establish in practical applications. Even if the nonlinear object can be modeled, the accuracy of the model cannot guarantee the accuracy. Knowledge-based approaches rely heavily on expert experience, which makes them less adaptable when new problems arise. With the continuous development of computer technology and machine learning algorithms, artificial intelligence is closely related to the research field of fault diagnosis, which provides a new direction for data-based fault diagnosis methods [4]. In the process of fault diagnosis, it is necessary to apply a variety of basic test technology knowledge. These include sensor technology, which is used to collect various parameters of the equipment during operation, such as force, temperature, pressure, sound and current, etc. In addition, signal processing technology is also crucial to filter and analyze the collected signal, extract the relevant time domain, frequency domain and time-frequency domain features that are conducive to fault diagnosis. It also can be used to extract useful information in the complex signal and identify the type of anomaly or fault. Fault diagnosis technology is widely used in the engineering field, mainly involving machine tools, presses, turbines, water pumps and other fields. Considering the simple and reliable of vibration signal analysis, the fault diagnosis based on vibration signal has attracted much attention. The following is a hydraulic equipment fault diagnosis as an example to illustrate the application of mechanical testing and signal processing technology in fault diagnosis.

2. Fault Diagnosis Case Study

2.1 Test System Composition

The fault diagnosis process can be summarized in the following six stages:

The first step is to build the corresponding simulation test bench according to the actual working environment of the test equipment, including the simulation of real working conditions and various experimental parameters to ensure the authenticity of the experiment and the accuracy of the data; In the second step, the corresponding vibration sensor is arranged in the main part of the equipment to be tested, and the appropriate position is selected according to the structure and working principle of the equipment, so as to ensure that the sensor can effectively detect the vibration signal; The third step is to use relevant test software to obtain the vibration signal generated during the working process of the equipment; The fourth step is the signal processing of these signals, which mainly includes the operation of filtering and noise reduction to improve the quality and accuracy of the signal, and prepare for the subsequent feature extraction; The fifth step is to extract the relative time domain, frequency domain and time-frequency domain features through mathematical methods and signal processing technology, which is used to analyze and identify the characteristics and rules of the fault signal; Finally, a fault diagnosis model is established based on the method of machine learning, and through training the model to identify and predict the possible fault types and locations of the equipment, so as to provide effective fault diagnosis and prevention measures. The flowchart of fault diagnosis is shown in Fig 1.

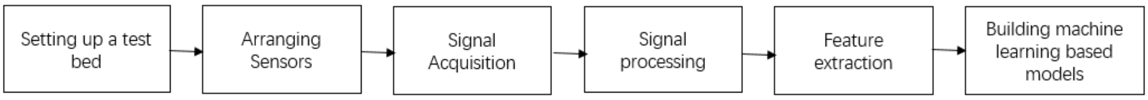


Figure 1: The flowchart of fault diagnosis system.

2.2 Operating Principle of Vibration Sensor

In order to ensure reliable fault diagnosis, it is necessary to select a suitable sensor to effectively collect vibration signals. Test technology is gradually developing in the direction of digitization and information, and the development of sensors as the forefront of test systems is also constantly breaking through. Vibration sensor, also known as vibration meter or vibration meter, can accurately record the mechanical vibration of the measured object, including displacement, speed and acceleration, and convert it into electrical signal output or display. From the point of view of energy conversion, vibration sensor realizes the function of converting mechanical energy into electrical energy.

Vibration sensors play a key role in mechanical equipment monitoring. It is mainly manifested in the following four aspects. In the first case, by monitoring the vibration of the equipment, the operating status and performance of the equipment can be evaluated in real time. The abnormal vibration can be detected in time, and equipment failure can be prevented. In the second case, vibration sensors are widely used to monitor the vibration of building structures, Bridges, pipelines and other engineering structures in the field of structural health monitoring. In the third case, fault diagnosis is another important application area of vibration sensors. By monitoring the vibration characteristics of equipment or structure, the possible fault causes can be identified and analyzed, and the fault diagnosis basis can be provided. In the fourth case, vibration analysis is another important application area of vibration sensors. By analyzing the frequency, amplitude, phase and other characteristics of the vibration signal, the vibration characteristics and motion state of the object are understood, and the reference is provided for engineering design and optimization.

2.3 Principle of Vibration Test System

The vibration test system of mechanical equipment is usually composed of several components to achieve accurate measurement and data acquisition of the vibration of the test equipment. The composition of vibration test system is shown in Fig.2. First, sensors are arranged on the surface of the test equipment to monitor vibration signals. The appropriate sensor type and number are selected according to the specific test requirements. The sensor is connected to the signal amplifier through a wire, and the function of the signal amplifier is to amplify the weak signal collected by the sensor to ensure the signal quality and stability. The signal amplifier is then connected to the data receiver via an Ethernet cable. A data receiver is a device used to receive and process signals collected by sensors and convert them into digital signals for storage and analysis. The use of Ethernet cable can achieve high speed and stability of data transmission, and ensure the timeliness and accuracy of data. Finally, the data receiver connects to the computer's corresponding data acquisition software via USB. Data acquisition software usually provides a dedicated interface for real-time monitoring of vibration data, performing data analysis and generating reports. Through USB connection, the data acquisition software can easily transfer the collected data to the computer for further processing and analysis.

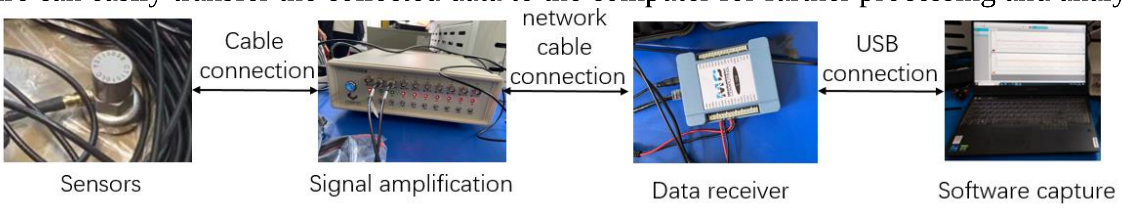


Figure 2: The composition of vibration test system.

3. Case Study

Selected the equipment is tested to obtain the corresponding normal data and fault data under various working conditions. At this time, the obtained data is only the corresponding data obtained in the time domain. Based on signal processing technology, commonly used data analysis methods can be divided into the following three categories: time domain analysis, frequency domain analysis and time-frequency domain analysis. The time domain analysis methods include time waveform analysis, envelope analysis and autocorrelation analysis. Frequency domain analysis includes fast Fourier transform (FFT), spectrum analysis and filter analysis. The methods of time-frequency domain analysis include continuous wavelet transform and time-frequency reconstruction. In this case, the

Fourier transform selected in frequency domain analysis is used.

As an efficient signal processing method, fast Fourier transform is widely used in communication, image processing, audio processing and other fields. It is an important technology in the field of signal processing, which can convert the signal from time domain to frequency domain and reveal the frequency domain characteristics of the signal. Fast Fourier transform algorithm reduces the computational complexity of Discrete Fourier Transform (DFT) from $O(N^2)$to $O(N \times logN)$, expressed as:

$$X\left(k\right)=\sum_{n=0}^{N-1}x_n e^{-jnk\frac{2\pi}{N}}, k=0,1,2,\cdots,N-1 \tag{1}$$

where x_n is a sequence obtained after sampling the target time domain signal at a certain frequency, $X(k)$ is the sum of the components of x_n with different frequencies and different coefficients. $e^{-jnk\frac{2\pi}{N}}$ is the basic rotation frequency, j is an imaginary unit (j^2=-1), k is the index frequency, n is a time (or space) index, N is the length of the sequence signal in the range of $N\geq 2$.

By converting the data in the time domain to the frequency domain, the following corresponding signal in the time domain can be compared with the signal processing in the frequency domain, as shown in Fig. 3.

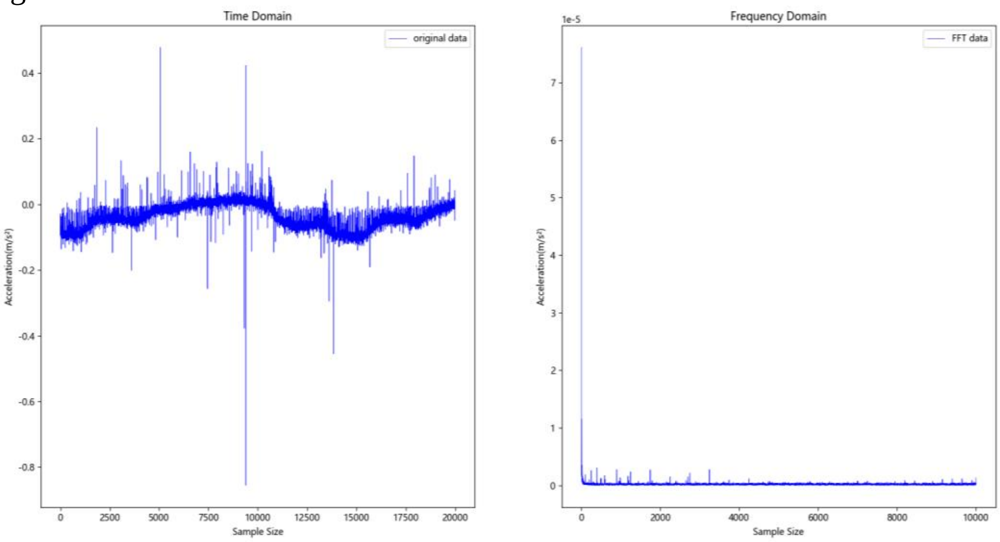


Figure 3: The comparison of time domain and frequency domain fault data.

The data in the time domain is converted to the frequency domain by the fast Fourier transform method to provide more detailed information for the fault diagnosis of the equipment. Then some linear and nonlinear index features are extracted from the data in the time domain and frequency domain. In this case, the dimensionality reduction algorithm based on feature extraction and principal component analysis are selected as the case algorithm. Principal component analysis (PCA) is a commonly used method for dimensionality reduction of data, while retaining the main information in the data. The main idea of principal component analysis is that the original high-dimensional data is projected into a new low-dimensional space by linear transformation, so that the projected data can maintain the maximum variance, expressed as:

$$X_{pca} = X.W \tag{2}$$

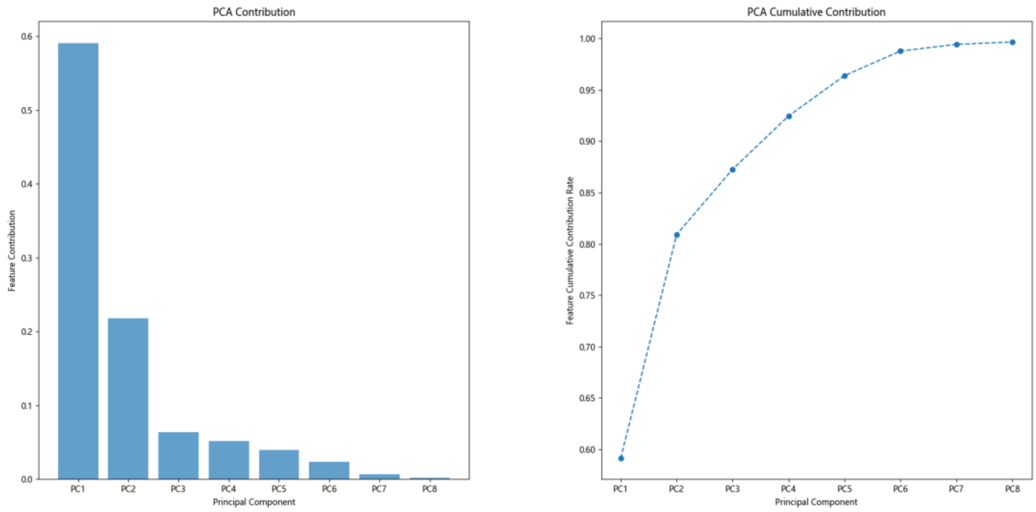
Where X is the feature matrix originally extracted, W is the mapping matrix composed of the corresponding eigenvectors according to the cumulative contribution rate X.

According to the calculation formula (3) of cumulative contribution rate, the features with cumulative contribution rate greater than 85% are selected as the new feature matrix after dimensionality reduction.

$$\eta = \frac{\sum_{k=1}^{i}\lambda_k}{\sum_{k=1}^{p}\lambda_k}(i = 1,\ \ 2, \dots, p) \tag{3}$$

Where p is the total number of features, i is the ith eigenvalue.

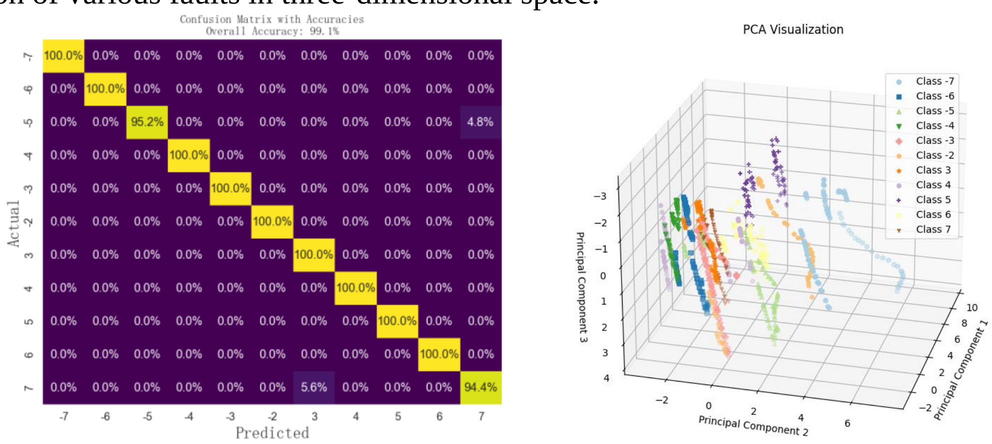
It can be seen from Fig. 4 (a) that features with a cumulative contribution rate greater than 85%. are selected as evaluation indicators for the selection of feature dimensions. So, the first three principal components are selected for subsequent fault diagnosis. Fig. 4 (b) shows the cumulative contribution rate.



(a)Principal component contribution degree (b)Cumulative contribution of principal components

Figure 4: The contribution degree.

Fault diagnosis of mechanical equipment is actually a classification or prediction task, and choosing the right machine learning algorithm can improve the accuracy of the model. In this case, support vector machine (SVM) is chosen as the demonstration method of mechanical equipment fault diagnosis, and the data after dimensionality reduction of principal component analysis is combined with SVM algorithm. As shown in Fig. 5 (a), the support vector machine method is used for fault diagnosis of mechanical equipment, with an accuracy of 99.1%. Fig. 5 (b) can clearly see the visualization of various faults in three-dimensional space.



(a) Confusion matrix of fault diagnosis (b) 3D viewable of fault diagnosis

Figure 5: Fault diagnosis result diagram.

4. Conclusion

In this study, we introduce a set of fault diagnosis analysis cases based on vibration sensor in detail, and confirm the feasibility of vibration sensor in mechanical equipment fault detection. By laying out multiple vibration sensors and obtaining multiple data from the equipment, we can not only obtain data under various operating conditions to judge the operating state of the equipment, but also predict the possibility of potential failures in advance. The purpose of this paper is to emphasize the importance of vibration sensor-based fault diagnosis in the engineering field.

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