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Fault Diagnosis of Gear Pump Based on Sparse Representation

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Abstract. A fault diagnosis algorithm of gear pump based on sparse representation is proposed in this study. The vibration signals of the faulty gear pumps are different from those of the normal ones. Therefore, by comparing the vibration signal of an unknown gear pump with the training signals form the normal gear pumps, its fault can be analysed and identified. The sparse representation is used in this study and the vibration signal of the test sample is linearly represented based on the dictionary formed by the normal signals. When the reconstruction error is large enough, the present gear pump is judged to be faulty. Otherwise, it is a normal one. Experiments are conducted based on some measured vibrations signals from both faulty and normal gear pumps. The results show the effectiveness of the proposed method.

1. Introduction

Pump plays an important role in a hydraulic system, which works in the conversion process of hydraulic energy. Owing to the advantages like high efficiency, low cost, and compact design, etc., gear pumps are widely used in modern industries. The status of a gear pump could significantly influence the whole hydraulic system. Therefore, it is desired that the fault occurred in gear pumps can be identified in time. According to previous researches [1-3], the conditions of a gear pump is closely related to the vibration signals resulted from the rotation. Hence, it provides a feasible way to diagnose the fault of gear pumps via the vibration signals [4]. In this field, some algorithms have already been designed for the fault diagnosis of gear pumps such as short time Fourier transform [5], wavelet transform [6], blind source separation [7], sparse decomposition method [8] and empirical mode decomposition (EMD) [9].

In this study, a fault diagnosis algorithm of gear pumps is proposed via sparse representation. At first, the vibration signal of a gear pump is collected as the basic feature for the fault diagnosis. For the faulty and normal gear pumps, they have notably different vibration signal patterns. Therefore, by analysing the differences, a faulty pump can be identified. In the detailed application, a dictionary combined by the vibration signals from normal gear pumps is established as the references. Then, for the gear pump to be judged, its vibration signal is linearly represented based on the dictionary, i.e., sparse representation. The reconstruction error from sparse representation actually reflects the difference between the tested gear pump and those normal ones in the dictionary. In this sense, when the reconstruction error is a very large one, the present gear pump is probably a faulty one. Otherwise, it tends to be a normal one. By comparing the reconstruction error with a predefined threshold T, the faulty gear pumps can be identified. In the experiments, 300 measured vibration signals from both the normal and faulty gear pumps are identified using the proposed method and the average accuracy reaches 93.24%. In comparison with other methods for fault diagnosis of gear pumps, the superiority of the proposed method can be validated.

2. Sparse Representation

2.1 Basic Theory

Sparse representation is an extension of linear representation, in which the coefficients are sparse ones. For an overcomplete dictionary $A=[A^1,A^2,\cdots,A^C]\in \mathrm{R}^{d\times N}$, which contains C different classes, it can effectively reconstruct a sample from arbitrary one of these classes. Then, the label of a test sample y can be probably identified based on the reconstruction errors resulted from different classes in the dictionary. The basic sparse representation problem is formulated as follow

$$\hat{\alpha}=\arg\min_{\alpha}\|\alpha\|_0 \quad \text{s.t. } \|y\text{-}A\alpha\|_2^2\le\varepsilon \tag{1}$$

In equation (1), α denotes the sparse coefficient vector. At present, some mature algorithms can be employed to get the approaching solutions to the optimization task in equation (1) such as ℓ_1-norm relaxation and orthogonal matching pursuit (OMP)

After obtaining the solution $\hat{\alpha}$ the reconstruction errors of different training classes can be calculated as follow.

$$r(i)=\|y\text{-}A_i\hat{\alpha}_i\|_2^2\,(i=1,2,\cdots,C) \tag{2}$$

In equation (2), $\hat{\alpha}_i$ and $r(i)$ are the coefficients and reconstruction error related to the $i\text{th}(i=1,2,\cdots,C)$ class.

For the specific use in this study, the reconstruction error of the vibration signal from a test gear pump reflects its relatedness with the dictionary. When the dictionary is formed by the vibration signals all from the normal gear pumps, a higher reconstruction error indicates that the present gear pump is more likely to be a faulty one. Therefore, by comparing the reconstruction error with a suitable threshold, the fault of the gear pump can be identified. Both the test sample and training samples are normalized before the sparse representation. So, the resulted reconstruction error is also a normalized one ranging from 0 to 1.

2.2 Procedure of Fault Diagnosis of Gear Pump

According to aforementioned analysis, the produce of fault diagnosis in this study is illustrated as Fig. 1. In detail, it can be summarized as following steps.

Step1: Build an overcomplete dictionary using the vibration signals from normal gear pumps;

Step 2: Represent the vibration signal of the test gear pump over the dictionary;

Step 3: Solve the sparse coefficients in Step 2;

Step 4: Calculate the normalized reconstruction error of the vibration signal from the test gear pump;

Step 5: Compare the normalized reconstruction error with a predefined threshold *T*. If the error is less than T, the gear pump is a normal one. Otherwise, it is a faulty one.

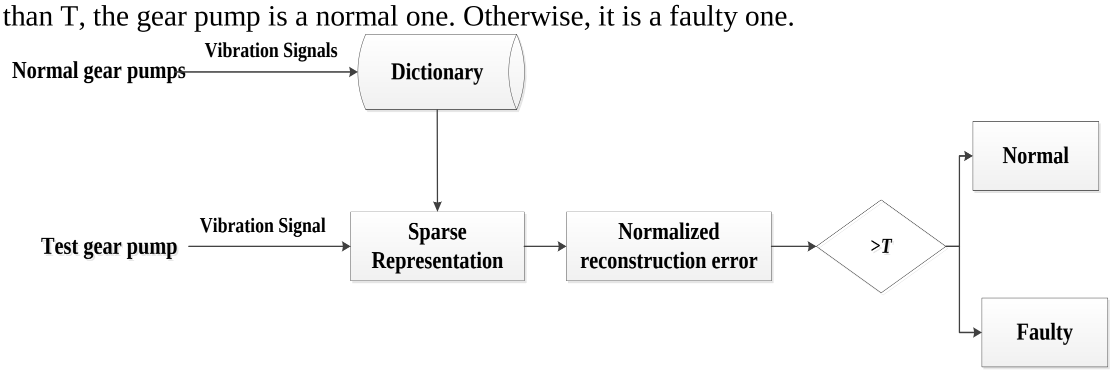

Fig. 1 Basic procedure of the proposed method.

3. Experiments

3.1 Data for Experiments

In order to test the performance of the proposed method, the data is first prepared by measuring the vibration signals from 300 gear pumps. For those gear pumps, 200 of them are faulty ones while the remaining 100 are normal. The dictionary for sparse representation contains 200 vibration signals form the normal gear pumps.

Some previous works in this field are adopted as the methods for comparison. In detail, they include the method from [4] (denoted as Method 1), method from [5] (denoted as Method 2), and method from [6] (denoted as Method 3). All these methods are performed simultaneously with the proposed method on the same dataset.

3.2 Results and Analysis

First, the proposed method is tested on the 300 vibration signals while the normalized threshold for identifying the fault gear pumps is set to be 0.4. 187 of the 200 faulty gear pumps and 94 of the 100 normal ones are correctly identified. So, the average accuracy reaches 93.67%. Table 1 compares the average accuracy of different methods. It is clear that the proposed method outperforms the remaining ones significantly. Therefore, the results validate the superior effectiveness of the proposed method.

Furtherly, the performance of the proposed method is tested at difference choices of normalized threshold as shown in Fig. 2. Accordingly, the highest accuracy of the proposed method occurs at 0.4, which is the main reason of using it in the former experiment. When the threshold is too small, some of the normal gear pumps will be judged to be faulty ones. On the contrary, a very large threshold may cause faulty gear pumps to be normal ones. According to Fig. 2, 0.4 is a suitable choice for the threshold.

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Table 1. Average accuracy of different methods.

Method	Proposed	Method1	Method2	Method3
Average accuracy (%)	93.67	90.85	91.82	90.38

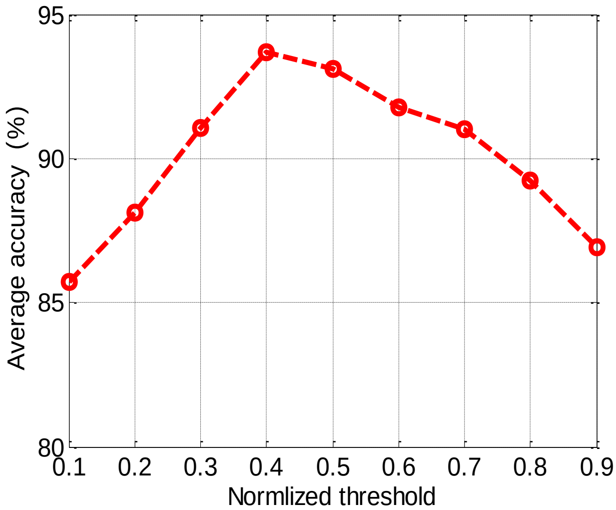

Fig. 2 The average accuracy of the proposed method at different thresholds.

4. Conclusion

This paper proposes a fault diagnosis method for gear pumps based on sparse representation. For a gear pump to be identified, its vibration signal is represented based on the dictionary formed by the signals from normal gear pumps. Based on the output reconstruction error, the fault of the gear pump is judged by comparing with a predefined threshold. Experiments are conducted on some measured vibration signals from both normal and faulty ones. The results show that the proposed method could achieve better performance than some other methods in this field.

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