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Vibration signal extraction method based on wavelet coefficient clustering

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Abstract

A lossless signal extraction method is proposed to deal with the enormous pressure on storage and transmission caused by massive signal data in the process of condition monitoring and evaluation of large equipment. The signal is sparsely decomposed by integer lifting wavelet transform. The decomposed wavelet coefficients are clustered and each group of data is coded in the form of "center code + differential code". Experiments show that the extraction scheme can effectively compress the vibration signal, and the extraction ratio is larger than 10:1. It can obviously save storage space and provide a new idea to relieve the pressure of signal storage and transmission.

Keywords

Vibration signal; Integer wavelet; Coefficient clustering; Signal extraction.

1. Introduction

The condition monitoring or fault diagnosis of large equipment (such as quayside bridge) needs to collect a large number of vibration signals for analysis [1]. Mechanical vibration signals are mostly dynamic, complex and non-stationary signals, which often cause massive data and bring some difficulties to communication. The state monitoring data is a sequence of data on the time axis, which usually contains a lot of redundant information [2]. Signal extraction can reduce the space occupied by signals and improve the transmission efficiency while retaining the effective features of signals in time and frequency domains. Aiming at the signal storage link in the remote condition monitoring and evaluation of mechanical and electrical equipment, a method of extracting and coding in the form of "center code + differential code" is proposed by utilizing the advantages of integer lifting wavelet transform, such as sparse decomposition, fast calculation speed and small memory occupation. It can effectively extract vibration signal data and preserve the time-frequency characteristics of complete vibration signal. Levy.

2. Integer Lifting Wavelet Decomposition

Traditionally, the allat algorithm used to construct wavelets takes up a lot of memory resources and produces a lot of floating-point numbers. Swelden proposed a new method of wavelet construction in 1994, lifting scheme [4]. On the basis of inheriting the multi-resolution characteristics of the first generation of wavelet transform, Swelden has the following advantages:

A) does not depend on Fourier transform;

B) It occupies less memory and calculates faster.

C) Integer-to-integer transformation and accurate reconstruction can be achieved.

The lifting wavelet decomposition process of vibration signal includes three steps: decomposition, prediction and update. Signals can be decomposed into arbitrary scales by repeated lifting schemes.

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The reconstruction process of lifting scheme is the inverse process of decomposition. Fig. 1 shows the decomposition and reconstruction process of lifting wavelet decomposition.

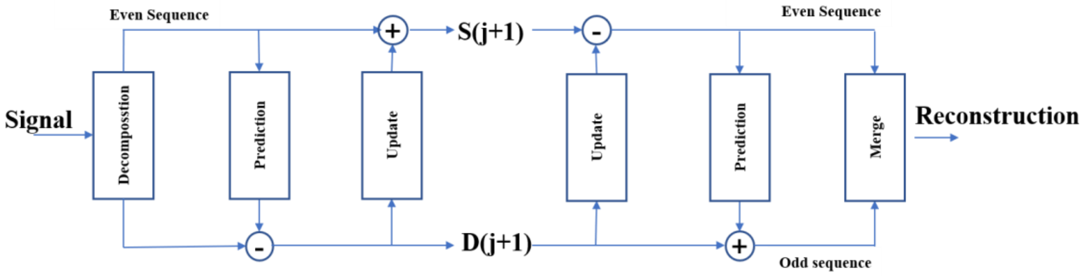

Figure 1. Decomposition and reconstruction process of lifting scheme

In the link of lifting wavelet prediction and updating, only the integer part of the wavelet coefficients can be preserved to achieve integer lifting. The suitable wavelet function can decompose the vibration signal into lower amplitude range and higher coefficient space with "0" ratio under the condition of occupying less memory, thus saving operation time and reducing bit occupation.

The selection of wavelet function largely determines the accuracy of feature extraction after wavelet decomposition. A large number of wavelet analysis studies on vibration signals in mechanical, electrical, civil and other fields [5] [6] [7] [8] [9] [10] [11] have proved that sym and DB wavelets have better performance in vibration signal feature extraction and data extraction. This paper compares the two wavelets for vibration signal decomposition.

3. Clustering algorithm

3.1 K-means clustering algorithm

Cluster analysis is a multivariate statistical method in statistics, which can automatically classify individuals according to the similarity of certain characteristics and produce multiple classification results. Before clustering, the number and type of individual classes are unknown. After clustering, the difference of individual characteristics within the class is small. K-means clustering algorithm is proposed independently by Steinhaus, Lloyd, Ball & Hall and McQueen in their respective scientific research fields. It is a simple and efficient clustering algorithm [14]. K-means algorithm first randomly selects K clustering centers and distributes other vibration signal data to each class according to the latest principle, then calculates K clustering and the average value of each cluster center separately, and iteratively redistributes individuals until there is no change, so as to get the final K classes. The steps of clustering coefficients of signals after wavelet decomposition are as follows:

(1) Integrate all wavelet coefficients into one data set.

(2) K objects are randomly selected as initial clustering centers in the data set.

(3) The residual wavelet coefficients are divided into the nearest cluster centers.

(4) After the distribution of the wavelet coefficients is completed, the average value of all the wavelet coefficients in each class is calculated as the center of the class.

If the result converges, the clustering result will be output; if not, step 2 will be returned for re-clustering.

3.2 Particle Swarm Optimization for Optimizing Initial Clustering Centers

Because the selection of initial clustering centers has a great influence on the clustering results of K-means algorithm, different initial clustering centers may produce different clustering results. Therefore, K-means algorithm is a greedy algorithm, easy to fall into local optimal solution, with volatility.

Based on K-means clustering algorithm of improved particle swarm optimization algorithm, the initial clustering center of K-means algorithm is optimized by using the global optimization ability

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of particle swarm optimization algorithm, and the dependence of K-means on the initial value of clustering center is eliminated [15]. Cluster centers are represented by particle positions. Each particle's location contains k clustering centers. The optimal clustering is obtained by adjusting the clustering centers. Particle swarm optimization is used to disturb the clustering centers so as to enhance the ability to jump out of local extremum and find the optimal clustering. If the clustering partition remains unchanged under multiple perturbations, the current clustering is considered as the optimal clustering. Particle Swarm Optimization (PSO) optimizes the initial clustering center flow as shown in Figure 2. The criterion function for evaluating the clustering effect of K-means algorithm is taken as the fitness function f(x) for evaluating the position performance of particles in particle swarm optimization (PSO). Then the fitness function of PSO can be defined as:

$$f(x) = \sum_j^k (\sum_{x_i \in C_j} \| x_i - z_j \|) \tag{1}$$

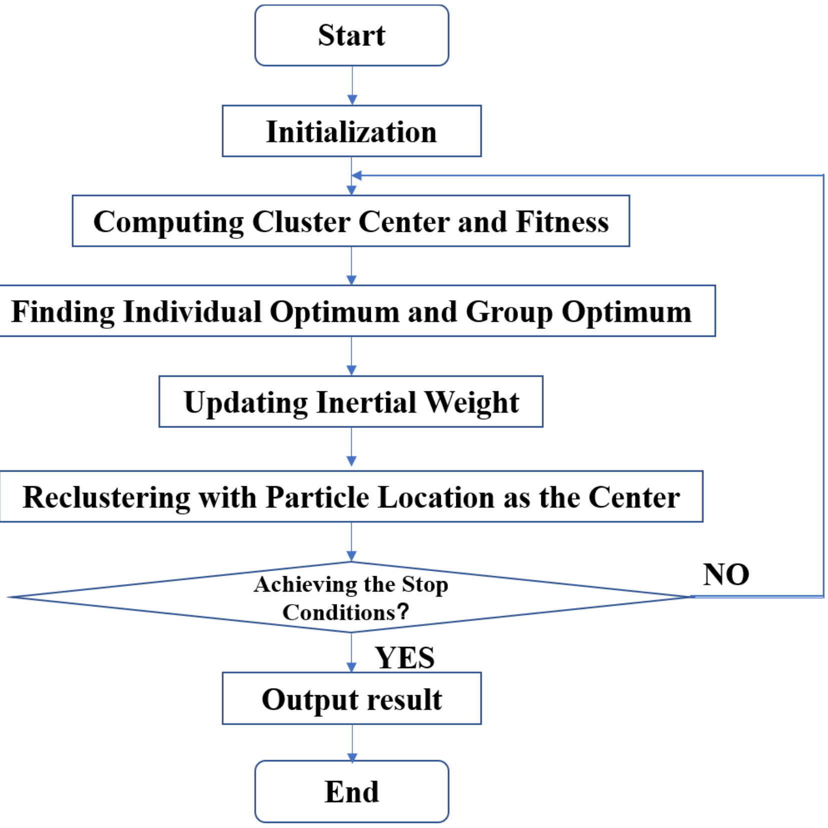

Figure 2. Particle swarm optimization for initial clustering center flow

4. Extracting and coding

Fixed-length encoding of data often wastes most data bits. The clustered wavelet coefficients get the clustering number based on the clustering results $i(1 \le i \le k)$,Based on the minimum value C_{min}^i of class i,the new data C_{new}^i of class i is obtained by making a difference between the data C^i and C_{min}^i of class i. For each vibration signal data, for the wavelet coefficients in class i, the occupied digits are:

B_i= Occupied figures of C_{min}^i + Number of digits occupied by cluster number i+ Binary digits occupied by class i differential data

Then the occupied digits of the extracted data are:

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$$B = \sum_{i=1}^{k} B_i$$

If the space occupied by the original vibration signal data is S, the extraction ratio is:

$$CR=S/B$$

The process of extracting vibration signal is shown in the figure 3:

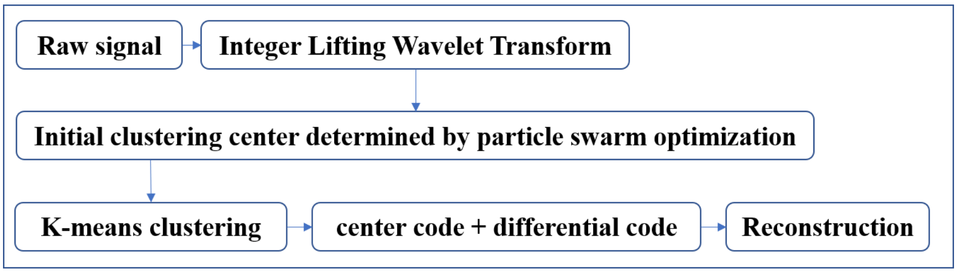

Figure 3. Nondestructive extraction process of vibration signal

5. Test and evaluation

The radial vibration signal of the motor is used as the extraction object in the experiment. The test parameters are in Table 1:

Table 1. Experimental parameters of motor radial vibration signal

Group number	speed / (r/min)	sampling frequency /Hz	Sampling points	Data size/byte
1	800	5000	20000	80000
2	1200	8192	32768	131072

Two sets of test signals are shown in the figure 4.

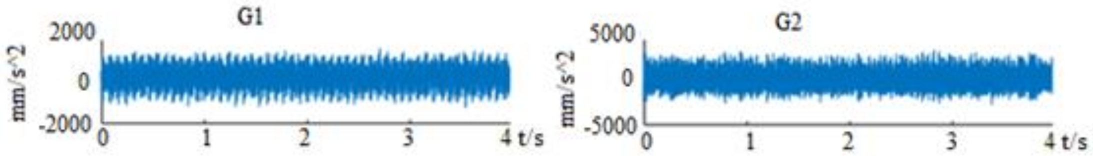

Figure 4. Two sets of test time domain signals

The parameters of the extraction algorithm and the extraction effect are shown in Table.2. From Table 2, we can see that the two groups of experimental extraction coding algorithms show good extraction effect, and there is no loss of information in the extraction process, which can effectively reduce the utilization of disk space of vibration signals. Because the vanishing moments and supporting lengths of db3 are both moderate, the decomposition coefficients of db3 wavelet are more in `0'elements, as shown in figure 5 and figure 6. It can obtain higher extraction ratio in shorter coding time.

Table2. Calculating parameters and extraction ratio

Group number	Cluster number	Acceleration Coefficient	Inertia weight	Wavelet type	Decomposition scale	Extraction ratio	Reconstruction error
1	8	(2, 2)	2	db3	5	12.6	0
				db3		11.7	0
2	15	(2, 2)	5	sym8	5	11.3	0
				sym8		10.1	0

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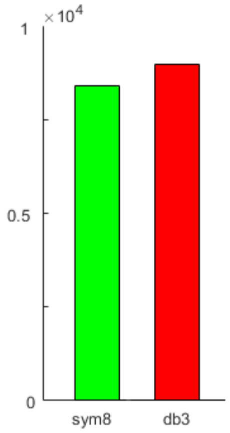

Figure 5. Group 1 Number of "0" Element Coefficients

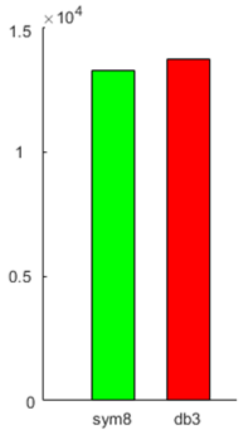

Figure 6. Group 2 Number of "0" Element Coefficient

6. Conclusion

Vibration signal extraction has important practical significance for engineering application. The optimization of K-means clustering algorithm by particle swarm optimization can effectively reduce the dependence of K-means algorithm on the initial value of clustering center. The coding scheme has a high extraction ratio for lossless extraction of vibration signals, which effectively saves data space. While optimizing the initial clustering centers of K-means algorithm has a good effect, determining the appropriate number of clustering centers will be the next research direction. Optimizing the operation time of clustering algorithm to improve the extraction efficiency is a hot issue worthy of further exploration.

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