Expert Systems with Applications 41 (2014) 4060–4072

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

An intelligent fault diagnosis system for newly assembled transmission

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ARTICLE INFO

Keywords:
Vibratory signal
Feature extraction
Fault classification
Order spectrum analysis
Genetic search algorithm
BP neural network

ABSTRACT

Newly assembled automobile transmission has its particular failure characteristic, strict quality testing working procedure on the assembly line is important for quality of automobile transmission. In this paper, we introduce a new automatic fault detection method for automobile transmission. A fault diagnosis expert system for newly assembled transmission is presented, related method of knowledge representation, feature extraction and fault classification is given. Order spectrum analysis method is used to analyze vibratory signal of automobile transmission. After initial feature vectors set are obtained, improved genetic search strategy is used to select fault features, so as to reduce the dimension of feature vector set. Selected feature vector sets are inputted into the BP neural network for fault identification and classification of the newly assembled automobile transmission. A large number of data are collected from industrial site and analyzed, proposed algorithm is verified to be effective and exact.

1. Introduction

Transmission as a main component of a modern automobile has a significant impact on vehicle performance, its technical parameters and working conditions is an important indicator to evaluate the automobile performance. There are a large number of quality problems caused by the transmission machining and assembly process. Failure of newly assembled transmission mainly include machining and assembly errors of the gear and shaft, such as gear deviation, the bearing assembly fault, assembly eccentric and gear burrs (Renaudin, Bonnardot, Musy, Doray, & Remond, 2010; Wang, 2007). For traditional transmission quality test, inspection work mainly rely on manual, this test method is called the original fault diagnosis, which depends on worker's feeling, hearing, and experience. The method cannot adapt to continuous, stable, efficient requirements of modern production, and it is difficult to locate failure to specific parts, and cannot provide transmission repair guidance. Existing research shows that fault analysis and signal processing method will determine efficiency and accuracy of fault diagnosis for automobile transmission. Commonly used methods include technology based on signal decomposition, such as Hilbert–Huang Transformation (HHT) (Rai & Mohanty, 2007; Su, Zhang, Jia, Xu, & Hu, 2011) and wavelet transformation (Hu, He, Zhang, & Zi, 2007; Yuan, He, & Zi, 2010), spectrum analysis, such as envelope spectrum analysis (Yang, Yu, & Cheng, 2007), as well as time-frequency analysis, such as order analysis (Cheng, Yang, & Yu, 2010).

Hilbert–Huang Transform is proposed by Huang (2005)). Main feature of HHT is Empirical Mode Decomposition (EMD), which is used to extract all the Intrinsic Mode Functions (IMFs) from non-stationary signals (Cheng, Yu, Tang, & Yang, 2008; Lei, He, & Zi, 2009; Liu, Riemenschneider, & Xu, 2006). While HHT is applied to process non-stationary signal, the "end effect" which propagates in the signal can make the performance worse, which is difficult to meet real-time requirements of diagnostic system for transmission test-bench. Wavelet transformation has more advantages than Fourier transformation. Wavelet transform can be used as a fine frequency signal decomposition method, but the choice of the wavelet basis function is not self-adaptive and wavelet transform is not adapted to process nonlinear signal analysis. A disadvantage of wavelet transformations is its relative complexity (Peng, Tse Peter, & Chu, 2005; Rafiee, Rafiee, & Tse, 2010; Rafiee & Tse, 2009). Envelope spectrum is suitable for analysis steady state speed, which is feasible to monitor transmission condition on the long-running the steady speed state, such as transmission fatigue testing. Newly assembled transmission on the test-bench is usually running in variable speed state, and accurate diagnosis results is difficult to get with fuzzy frequency obtained by envelope spectrum (Yang et al., 2007). Order analysis can make up for shortcoming of envelope spectrum analysis, uniform time sampling is transformed to uniform angular sampling by time-frequency signal synchronous acquisition, which meet fault diagnosis requirement for transmission in variable speed state. Order analysis has quickly process speed, and meets real-time requirements (Bai, Huang, Hong, & Su, 2005).

Fault diagnosis algorithm for automobile transmission can be divided as feature extraction, feature selection and fault classification. Many researchers have presented different algorithms for

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http://dx.doi.org/10.1016/j.eswa.2013.12.045

feature selection and fault classification. Li, Zhang, Tian, Mi, Liu and Ren (2011) proposed a novel feature extraction and selection scheme for hybrid fault diagnosis of gearbox based on S transform, non-negative matrix factorization (NMF), mutual information and multi-objective evolutionary algorithms. A two stage feature selection approach combining filter and wrapper techniques based on mutual information and non-dominated sorting genetic algorithms II (NSGA-II) was presented to get a more compact feature subset for accurate classification of hybrid faults of gearbox. Hajnayeb, Ghasemloonia, Khadem, and Moradi (2011) designed a system based on artificial neural networks (ANNs) to diagnose different types of fault in a gearbox. The system was optimized by eliminating unimportant features using a feature selection method (UTA method). This method of feature selection was compared with genetic algorithm (GA) results. The findings verify that the results of the UTA method are as accurate as GA, despite its simple algorithm. Wu, Hsu, and Wu (2009) presented an intelligent diagnosis for gear fault identification and classification based on vibratory signal using discrete wavelet transform and adaptive neuro-fuzzy inference system (ANFIS). The proposed ANFIS includes both the fuzzy logic qualitative approximation and the adaptive neural network capability. Although, much has been done on the methods or expert system of fault detection for gearbox recently (Jayaswal, Verma, & Wadhwani, 2011; Lei, Zuo, He, & Zi, 2010; Li, Yan, Yuan, Zhao, & Peng, 2011; Saravanan, Cholairajan, & Ramachandran, 2009), little attention has been paid to fault detection of newly assembled automobile transmission, which is different from gearbox used for a long time. The main differences include: (1) Newly assembled automobile transmission has different fault types from gearbox used for a long time. (2) Vibration of newly assembled transmission is non-stationary, time-varying signal. (3) Particularly challenging research work is that fault signal of newly assembled transmission is relatively weak, which is not easily collected. (4) Fault diagnosis algorithm should be fast to adapt to the quick quality inspection procedure in automobile transmission assembly line.

Most of the related algorithms mentioned above are not suitable for fault diagnosis method based on order analysis. The objective of this paper is to study fault diagnosis method for newly assembled automobile transmission. Synchronous data acquisition algorithm of the vibration signal and the speed signal is proposed in this paper, which provides accurate data for latter order calculations, and so far, no same practical algorithm can be searched. We also proposed the improved FFT algorithm which is used for spectral transformation after a lot of tests. The expert system discussed in this paper focuses on establishing a knowledge base, proposing feature extraction, feature selection and fault classification algorithm for newly assembled automobile transmission. Fault diagnosis system for newly assembled transmission proposed in this paper is integrated innovative work. There is no relevant literature to be investigated.

The detailed section is organized as follows: A fault diagnosis system structure for newly assembled transmission is proposed, and method of data acquisition, data pre-processing, and feature vector extraction and knowledge representation is described in Section 2. Genetic algorithm for feature selection is designed in Section 3. Fault classification method with BP neural network is described in Section 4. Method proposed in this paper is tested and analyzed in Section 5. Conclusion and future works are discussed in Section 6.

2. Transmission knowledge representation and feature extraction

The fault diagnosis system is used to acquire transmission vibratory signal, analysis data, and provide quality evaluation results. The system is composed of five modules: data acquisition, time-domain analysis, learning and training, on-line detection, data store, which is shown in Fig. 1. The functions include parameters configuration, data acquisition, digital filter, time-frequency transform, angular-frequency transform, power spectrum, order transform and feature extraction.

The fault diagnosis system is run in two modes: learning and training, on-line detection.

(1) Learning and training: a certain number of qualified and faulty gearboxes are used to train system, namely teacher-training. In this mode, system will automatically acquire and store system parameter, which is used for on-line fault detection.
(2) On-line detection: in this mode, system will use pre-training diagnostic model to analyze gearbox signal acquired on-line, and give fault detection results. Newly discovered type of fault will be stored and used for training system again, so new type of fault can be detected.

2.1. Data acquisition and pre-processing

The purpose of data acquisition is to acquire vibratory signal by sensor and transform it into signals which can be processed and

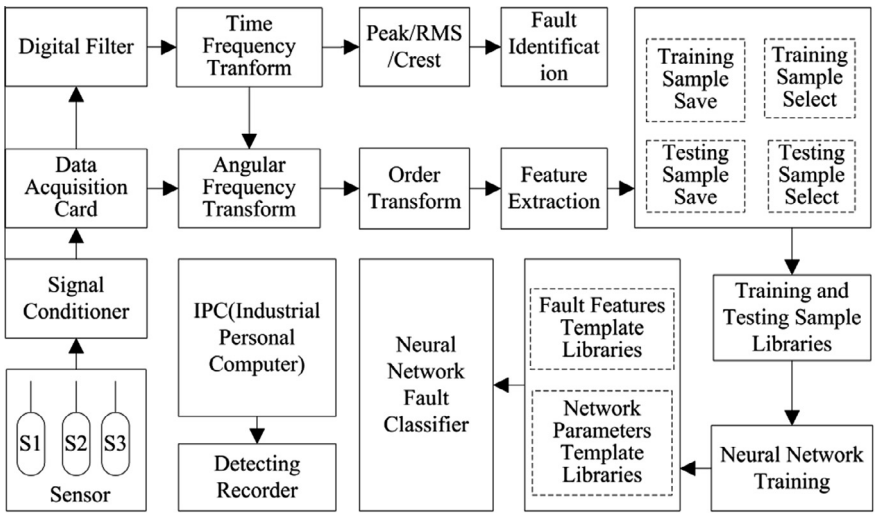

Fig. 1. Fault diagnosis system for automobile transmission.