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論文内容の要旨

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題 目 Deep Learning Based Intelligent Diagnosis Methods for Rotating Machinery Using Vibration Signal - Approach by Signal Preprocessed SAE and Improved CNN -
(ディープラーニングと振動信号に基づく知的回転機械診断法―SP-SAEとI-CNNによるアプローチ―)

The rotating machinery plays an indispensable role in the increasing high-speed, precise, large-scale and automatic modern industrial systems. The unexpected fault can result in serious loss of safety, property, and environmental destruction. Therefore, it is a great importance to perform the health management through a high-precision fault diagnostic system that can learn the available information to identify tiny faint faults in early stage, to give detection and diagnosis of fault information and provide support for crucial decision for maintenance. This thesis focus on intelligent fault diagnosis based on deep learning since it has superiority in terms of its self-adaptive feature learning capacity, multilayer nonlinear mapping ability and the potential to handle large mechanical datasets. And the detailed research content is as follows:

(1) Since the raw signal collected from the sliding bearing is contaminated with background noise, and it is difficult to obtain high-precision results for the traditional methods due to the low signal-to-noise ratio (SNR). Therefore, a stepwise intelligent diagnosis method based on statistical filter and stacked auto-encoder (SAE) is proposed for sliding bearing in a rotor system. Firstly, the statistical filter is utilized to reduce the interference information for increasing the SNR. Secondly, the stepwise intelligent diagnosis based on SAE is performed to learn the useful fault features and automatically complete the sliding bearing fault diagnosis. Finally, the thesis presents detailed experiments to indicate the feasibility and effectiveness for performing high-precision fault diagnosis compared with other several methods.

(2) A novel method of intelligent diagnosis is proposed for structural faults in low-speed rotating machinery. It uses a hybrid scheme to automatically identify health states in a complex mechanical system by combining an improved mode decomposition approach, a Gramian angular summation field (GASF) and a convolutional neural network (CNN). The proposed method is tested with a dataset affected by noise to evaluate its performance and generalizability, which are both essential in fault diagnosis. Experimental results show that the proposed scheme is superior to traditional machine learning methods. Finally, the reasons for the high performance are analysed to determine the best general features for an adaptive classifier that is generalizable to diverse operating conditions.

(3) Machinery fault diagnosis is an attractive but challenging task, especially for low-speed conditions. Therefore, a new discriminative approach that introduces robust principle component analysis (RPCA) and multi-kernel to deep neural networks is proposed to perform intelligent fault diagnosis. Firstly, RPCA is applied to extract fault signals from extreme background noise based on its sensitivity to grossly corrupted data. Secondly, two cascaded MKPCA stages with additional robustness

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to distortions in feature extraction are used to enhance the energy of spectrum symptom and overcome the tricky issues of low-speed machinery. Especially, the multi-kernel is introduced into the basic PCA filters to learn the data-adapting convolution filter and gain additional robustness to nonlinearity in the signal. Finally, the proposed method is demonstrated on signals from laboratory tests (with a slightly damaged defect in a bearing) and structural fault data, outperforming those of traditional machine learning and classical deep learning methods. Moreover, hidden information of the network is visualized to analyse the reasons for its high performance.

(4) For timely detection of bearing and structural fault, an intelligent fault diagnosis method based on multiclass convolutional neural network (MCNN) has been proposed to investigate the vibration and current signal for identifying those faults in complex rotor system. Firstly, the vibration and current signal (three bearing faults, three structural faults and normal state) were recorded simultaneously under steady-state for each operation condition (three vibration speeds). Secondly, the signal processing technique is chosen to solve the problem of modeling noise instances as true underlying relationship for MCNN. Finally, a one-versus-one and a comprehensive MCNN have been trained with both signal at various operating conditions individually and collectively, respectively. And the experimental results revealed that the accuracy of the vibration signal is better than the current signal whether it is structure faults or the external bearing faults. Moreover, the fault diagnosis performance is investigated for the wide range of MCNN parameters and selected the best result for one optimal parameter for a one-versus-one and a comprehensive MCNN. The experimental results shown that the vibration signal of the bearing with the high-pass filter and envelop has stable accuracy when changing the parameters in the MCNN.