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An Image Processing Approach to Machine Fault Diagnosis Based on Visual Words Representation

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Abstract

Machine fault diagnosis and remaining service life prognosis provide the basis for condition-based maintenance, and is key to operational reliability. Accurate assessment of machine health requires effective analysis of vibration data, which is typically performed by examining the change in frequency components. One limitation associated with these methods is the empirical knowledge required for fault feature selection. This paper presents an image processing approach to automatically extract features from vibration signal, based on visual words representation. Specifically, a time-frequency image of vibration signal is obtained through wavelet transform, which is then used to extract "visual word" features for recognizing fault related patterns. The extracted features are subsequently fed into sparse representation-based classifier for classification. Evaluation using experimental bearing data confirmed the effectiveness of the developed method with a classification accuracy of 99.7%.

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Keywords: Condition Monitoring, Pattern Recognition, Reliability Engineering

Introduction

Through-life Engineering Services (TES), which provides support through the product design, manufacturing, redesign, remanufacture, recycle and reuse stages, has become an integrated part of the product lifecycle itself, as illustrated in Fig. 1 [1]. It takes input from the knowledge of design function, manufacturing method, degradation

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mechanism, fault diagnostics and remaining service life prognostics, and brings benefits to all product lifecycle stages.

Being a key element in the use phase of the TES, machine condition monitoring contributes to the overall manufacturing sustainability, by 1) providing technical base for operation and maintenance decision making for improved operational reliability and efficiency and 2) providing information to optimize product design and extend its service life based on the usage experience. The theoretical analysis of the machine failure mechanism has helped researchers gain the knowledge of fault detection and diagnosis when a machine deviates from its normal operating condition, leading to the traditional diagnosis techniques based on the manual extraction of the fault-related patterns in the signal's time-frequency spectra that match the analytical or empirical knowledge of the fault [2].

As the manufacturing industry embraces Big Data era, the specific analytical and empirical knowledge of fault mechanism and corresponding reflections on measured sensor data quickly become elusive with respect to arbitrary application scenarios. The task can be further complicated by the addition of fault severity level diagnosis [3]. Furthermore, with the continuous increase of the sensing data size in today's manufacturing industry, it is imperative to have an automated system to facilitate data processing [4-9].

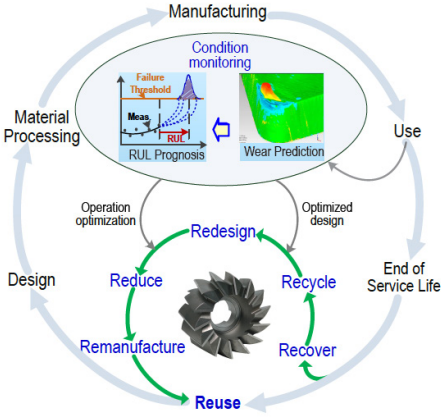

Fig. 1 TES as the concept of service support within the product lifecycle [1]

In this paper, a new integrated method based on wavelet transform and visual words representation, an image processing technique for image spatial pattern analysis, is proposed as an attempt to extend the traditional feature extraction method and represent a potential path to effective, automated time-frequency analysis for fault diagnosis, as images share common properties with manufacturing data such as high dimensionality and high variation [7-9].

The contribution of this research is to extend the capability of detecting and representing local patterns in time-frequency spectra, which are different among various machine health status, from the traditional manual procedure to two automated steps: point of interest detection and pattern description. Analogous to finding the peaks in frequency spectrum, the detection stage involves searching for local extremum in pixel intensity as the point of interest, representing signal characteristics in the time-frequency domain. The pattern description stage involves building a descriptor for each point of interest to describe the distribution of the pixel intensity within its neighbourhood, enabling the capture of a more complete morphological pattern of the signal in the time-frequency domain. Finally, k-means is applied as "feature fusion" to produce visual words clusters as sparse "visual words" feature vector. Visual words representation is a shift, scale and rotation invariant technique, enabling robust point of interest detection and feature comparison [11-13]. By integrating wavelet transform with visual words representation, the advantages of wavelet transform in capturing fault related patterns in the time-frequency domain, given its multi-resolution decomposition capability [14-16], and visual words representation of the converted 2D images are synergistically integrated. The generated visual words feature vectors are subsequently fed into a sparse representation based classifier (SRC) for simultaneous fault type and severity classification due to its simplicity and reliability [17-19].

The remainder of the paper is organized as follows. The theoretical framework of the continuous wavelet transform, the visual words representation and SRC are first introduced in Section 2. Section 3 investigates the effectiveness of the proposed method for bearing fault diagnosis. Conclusions are provided in Section 4.