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Modified self-organising map for automated novelty detection applied to vibration signal monitoring

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Abstract

This paper proposes a novelty detection-based method for machine condition monitoring (MCM) using vibration signals and a new feature extraction method based on higher-order statistics of the power spectral density. This novel MCM method is based on Kohonen's self-organising map and adopts a multidimensional dissimilarity measure for dual class classification. The approach is designed to be highly modular and scale well for a multi-sensor condition monitoring environment. Experiments using real-world vibration data sets with upto eight sensors have shown high accuracy in classification and robustness across different condition monitoring applications.

Keywords: Condition monitoring; Vibration signal processing; Features extraction; Higher-order statistics; Novelty detection; Artificial neural network; Self-organising map

1. Introduction

Machine condition monitoring (MCM) is an area of engineering which has been undergoing a transformation from a predominantly manually based monitoring approach to a highly

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automated approach where manual intervention is only required in the event of a fault being detected. This push has created a need for techniques that are capable of automatically identifying when machine deviates from a normal condition. Many approaches have been advanced in this respect, from basic thresholding of vibration levels (probably the most commonly used), through fuzzy logic and neural-network-based learning approaches [1–7].

One of the main problems inherent in the current supervised neural network approach is that training data from all classes are required during the training phase of the supervised neural network. Class labels are essential in order for the decision boundaries to be drawn. However, the problem in the MCM environment is that often only sufficient information from one class may be available. The system must be able to detect when the machine condition deviates from a ''Normal'' condition, and hence raise a warning. This issue is further complicated by the fact that throughout the natural life cycle of a machine, the vibration characteristics will naturally change, and any system used must be capable of dealing with this as part of the normal operation of the system.

Most current approaches using spectrally based features tend to use either very high-resolution power spectrum or very low-resolution power spectrum. Each approach has its own advantages and disadvantages; the high-resolution approach can very accurately identify the onset of a failure in a machine, however this is at the expense of high computational cost and storage cost. Additionally, in any pattern recognition context, a high dimensional training environment requires a significant number of training examples to provide a meaningful training sample estimate. This situation can be improved by using lower dimensional input data; although low-resolution approaches can characterise general trends in spectra, often the low resolution is insufficient to indicate the onset of a fault condition accurately. The spectral spread of the low-resolution approach tends to mask fault frequencies.

In this paper, detection is carried out using a modified Self Organising Map (SOM), as first proposed by Kohonen [8]. The SOM has become one of the most commonly used ANNs; its most common application lies in feature generation through high dimension mapping and data visualisation [9–11]. In this work, a modified SOM-based novelty detector is proposed for use in the MCM problem. With this new architecture, training data from only one class is used to detect deviation from that class, assuming that the training data is an adequate representation of the sample distribution. Further refinements are added to the algorithm to allow it to operate for multiple sensors, and provide an overall indication of the likelihood of a fault being present on the basis of the results returned from each sensor.

A new statistics-based feature set of the power density spectra is also introduced in this work. The new feature set is aimed to strike a balance between good resolution and reduced dimension complexity. Dimension reduction is done implicitly via this new feature extraction technique.

The article is organised in the following way. Section 2 provides a brief introduction to SOM and the modification made to the algorithm for this application. The new feature generating techniques are discussed in Section 3. Section 4 describes the two data sets chosen for experiments, while Section 5 details the experiment training process of SOM. However, performance comparison with results from our previous works cannot be done directly due to the different features set used in this work. Nevertheless, Section 6 provides a good indication of the capability of the proposed method through the experimental results presented.