Expert Systems with Applications 39 (2012) 2082–2091

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

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

Intelligent fault diagnosis of rotating machinery using infrared thermal image

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ARTICLE INFO

Keywords:
Thermal image
Feature selection
Fault diagnostics
Intelligent diagnosis system

ABSTRACT

This study presents a new intelligent diagnosis system for classification of different machine conditions using data obtained from infrared thermography. In the first stage of this proposed system, two-dimensional discrete wavelet transform is used to decompose the thermal image. However, the data attained from this stage are ordinarily high dimensionality which leads to the reduction of performance. To surmount this problem, feature selection tool based on Mahalanobis distance and relief algorithm is employed in the second stage to select the salient features which can characterize the machine conditions for enhancing the classification accuracy. The data received from the second stage are subsequently utilized to intelligent diagnosis system in which support vector machines and linear discriminant analysis methods are used as classifiers. The results of the proposed system are able to assist in diagnosing of different machine conditions.

1. Introduction

Rotating machinery covers a broad range of mechanical equipment and plays a significant role in industrial applications. Due to the necessity of increasing production, rotating machinery is essentially required to run continuously without interruption and to extend the machine life as well (Saxena & Saad, 2007) due to the fact that its failures has become very costly and time consuming. Hence, a great emphasis on machine fault diagnosis is necessary to increase the availability and to avoid personal casualties as well as economic losses (Lei, He, & Zi, 2009). However, with rapid development of science and technology, rotating machinery in modern industry is growing larger, more precise, and more automatic. Its potential faults become more difficult to detect. Therefore, the need to increase fault diagnosis capability against possible failures has considerably attracted numerous researchers in recent years. Different approaches for condition monitoring and diagnosis of rotating machinery have been profitably proposed in literature such as acoustic emission (Toutountzakis, Tan, & Mba, 2005), vibration analysis (Yang, Lim, & Tan, 2005), frequency analysis (Lee & White, 1997) and other methods which are suitable only for a particular machine.

Infrared thermography is a non-contact and non-intrusive temperature measuring technique with an advantage of no alteration in the surface temperature and capable of displaying real time temperature distribution. This has been exploited in many industrial and/or research fields, amongst other: meteorology, environment, medicine, architecture, engineering where the temperature represents a key parameter. The measurement principle is based on the fact that any physical object radiates energy at infrared wavelengths i.e. within the infrared range of the electromagnetic spectrum. Thermal camera can measure and visualize emitted infrared radiation evoked. Therefore, the surface temperature distribution is recorded in the form of thermogram. Basing on this characteristic, thermal image is currently applied to machine condition monitoring and diagnosis field.

In order to monitor the conditions as well as diagnose the machine faults, signal processing techniques are firstly required to process the data acquired from machine. The early one of these techniques which frequently uses for processing one-dimensional signals is fast Fourier transformation (FFT). FFT is also employed as an image processing tool to handle of two-dimensional (2D) signals i.e. X–ray, synthetic aperture radar (SAR), magnetic resonance image (MRI), and RGB image, etc (Brigham, 1988; Gonzalez & Woods, 1993). Currently, wavelet transformation has been received much consideration for image processing field. An outstanding of this technique is 2D discrete wavelet transform (2D-DWT) commonly used as a decomposition algorithm. However, the data obtained from the decomposition process are rarely usable due to the huge dimensionality which causes not only difficulties of data storage but also data processing for the next procedure. Representing data as features is the effective solution for this problem. Representing data as feature or dimensionality reduction is a process of extracting the useful information to remove artifacts and reduce the dimensionality. However it must preserve as much as possible the characteristic features which indicate the conditions and faults of machine. Dimensionality

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doi:10.1016/j.eswa.2011.08.004

reduction, which is an essential data preprocessing technique for classification tasks, traditionally fall into two categories: feature extraction and feature selection.

In machine fault diagnosis, there have been numerous pproaches for dimensionality reduction such as independent component analysis (ICA), principal component analysis (PCA) (Widodo & Yang, 2007), genetic algorithms (Siedlecki & Sklansky, 1989) and relief algorithm (RA) (Kira & Rendell, 1994).

In the case of using image processing techniques, our previous work proposed a feature extraction technique based on histogram for 2D thermal image to diagnose the faults of machine (Younus & Yang, 2010). In this study, the Mahalanobis distance (MD) and RA based feature selection is investigated with the aim of improving the classification performance. Subsequent to dimensionality reduction procedure, selecting the models for classification or diagnosis task is carried out for the next stage. These models have a wide range of approaches which are varied from model-based to pattern recognition-based. Amongst these approaches, artificial intelligence (AI) techniques based machine fault diagnosis system has become popular in which numerous methods have been completely employed, for instance support vector machines (SVM), multi-agent fusion system, expert system, artificial neural networks, and fuzzy logic (Grossmann & Morlet, 1984; Niu, Han, Yang, & Tan, 2007; Patel, Khokhar, & Jamieson, 1996). Similarly, a diagnosis system based on AI techniques in association with potential signal processing and feature selection technique is investigated in this study. The AI diagnosis models used here include linear discriminant analysis and SVM for classifying the different classes of machine conditions such as normal, misalignment, mass unbalance, and bearing fault from thermal images. The results of the proposed system could able to assist greatly in diagnosing the different machine conditions.

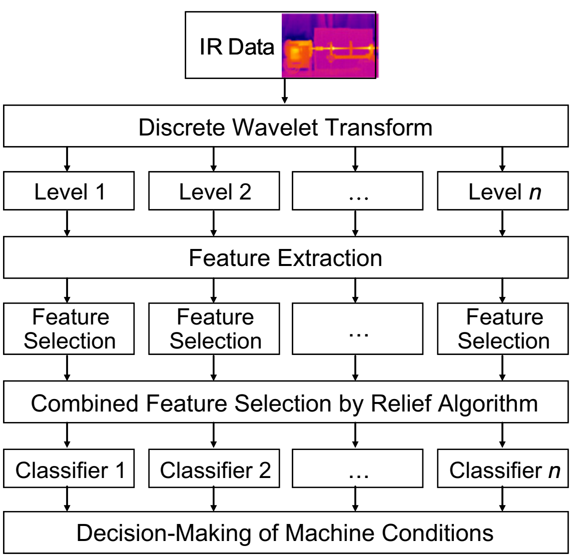

Fig. 1. Architecture of IDS.

2. Architecture of the proposed system

The proposed intelligent diagnosis system (IDS) consists of consequent procedures: image decomposition, feature calculation which is used to represent obtained data as features, feature selection, and classification algorithms as shown in Fig. 1. Thermal images captured the machine conditions which are normal condition, misalignment, mass unbalance, and bearing fault are utilized as the input for this system. Initially, the measured data are driven into 2D-DWT to calculate the wavelet coefficients. Then, these huge data are passed through the feature calculation module where feature sets are obtained by using different statistical feature algorithms. For example, standard deviation, mean absolute deviation, kurtosis, skewness, and others are adapted in this study. However, after this procedure, the received data are normally high dimension and have a large amount of redundant features. If these data are directly inputted into the classifiers, the performance will be significantly decreased. Therefore, feature selection algorithm should be employed in order to choose the appropriate features which can characterize the machine conditions from the whole feature sets and transform the exiting feature into lower dimensional space. In IDS, feature selection module is built up by two steps where only a selected number of feature sets are being used to obtain accurate results regarding the machine conditions. The first step is applied to find the levels that contain significant features. Subsequently, the obtained features from the first step are combined with a data sheet from where the features sets are found by applying RA in the second step. Finally, the selected features from different level of coefficients are combined and then inputted to the classifiers. Two different classifiers are embedded in IDS to evaluate the system performance.

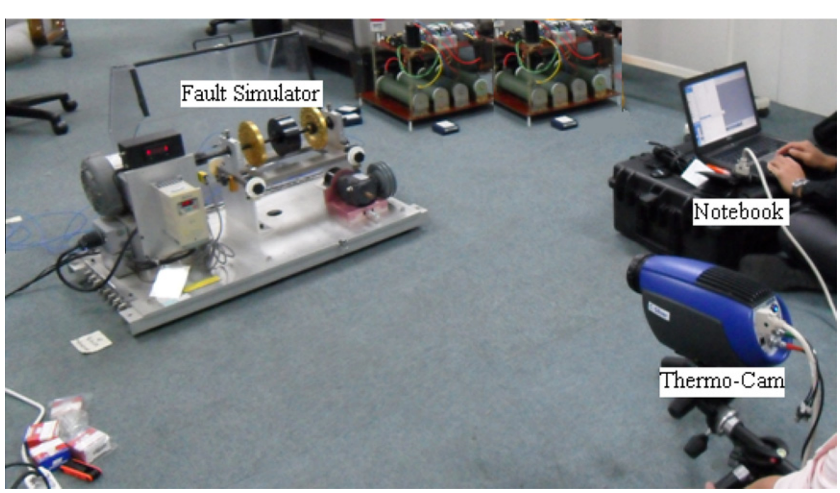

Fig. 2. Experimental setup.