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Wavelet support vector machine for induction machine fault diagnosis based on transient current signal

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Abstract

This paper presents establishing intelligent system for faults detection and classification of induction motor using wavelet support vector machine (W-SVM). Support vector machines (SVM) is well known as intelligent classifier with strong generalization ability. Application of nonlinear SVM using kernel function is widely used for multi-class classification procedure. In this paper, building kernel function using wavelet will be introduced and applied for SVM multi-class classifier. Moreover, the feature vectors for training classification routine are obtained from transient current signal that preprocessed by discrete wavelet transform. In this work, principal component analysis (PCA) and kernel PCA are performed to reduce the dimension of features and to extract the useful features for classification process. Hence, a relatively new intelligent faults detection and classification method called W-SVM is established. This method is used to induction motor for faults classification based on transient current signal. The results show that the performance of classification has high accuracy based on experimental work.

Keywords: Wavelet support vector machines; Fault diagnosis; Transient current signal; Component analysis; Induction motor

1. Introduction

Induction motor is an essential component in many industrial processes which deals with moving and lifting products. Special attention is urgently required in condition monitoring of induction motors in order to guarantee its stable and high performance. By applying early fault diagnosis of operating induction motors which give incipient fault condition, little effort to overcome such fault can avoid more serious conditions (Siyambalapitiya & McLaren, 1990).

There are many techniques have been implemented as tools for condition monitoring and fault diagnosis of induction motors aiming at providing high-degree of reliability and prolonging the motor lifetime (Chen, Zhong, & Lipo, 1994; Tavner, 1989). It has been shown that large number of electromechanical systems are equipped with mechanical sensors; primarily vibration sensor based on either accelerometer or proximity probe. Therefore, those methods are quite expensive and delicate. Moreover, in many situations, vibration signature measurement is performed to detect the presence of incipient failure. However, it has been suggested that the stator current monitoring can provide the same indication without requiring access to the motor. This method utilizes results of the residual current waveform (after filtering) of the induction motor to spot an existing or incipient failure which in turn can be used for faults diagnosis (Douglas & Pillay, 2004).

Many methods have been developed using motor current signature analysis (MCSA) to perform condition monitoring and faults detection of induction motors. A brief review discussing how to use MCSA was highlighted in Benbouzid (2000) and Nandi and Toliyat (1999). Detection of different machine faults under steady state operating condition has been improved over the past decade. It has been found that these techniques are effective only when the machine being diagnosed is almost fully loaded and

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running at constant speed (Douglas & Pillay, 2005). Those techniques are less accurate when applied to slightly loaded, start-up process or under transient condition such as the wind generator and the motor operated valves.

Most of research of fault diagnosis of induction motor using transient current are based on experimental work and followed by signal processing such as filtering, wavelet transform, etc. It is difficult to analyze the transient current signal, e.g. frequency component, which related to fault in induction motors. Transient current signal is generated when the machine starts up and then the slip changes when the machine runs up (Douglas & Pillay, 2004). So the analysis of the frequency component related to fault becomes difficult. The analysis of the frequency component is relatively easy when the machine runs at constant speed or the steady state condition. There are various methods to detect induction motor faults using the frequency analysis such as those resulting from air-gap eccentricity, broken rotor bars, or bearing damage.

The application of intelligent system for condition monitoring and fault diagnosis is widely used for many areas. Support vector machines (SVMs), developed by Vapnik (1999), have been extensively employed to solve classification problems due to the excellent generalization performance on a wide range of problems (Yang, Han, & Hwang, 2005; Yang, Hwang, Ko, & Lee, 2005). Compared with artificial neural network (ANN), SVM does not suffer from problems such as local minimization, the problem of selecting nodes in the hidden layer and the dimension curse. SVM which is based on statistical learning theory is widely gaining application in the area of machine learning, data classification and pattern recognition because of the high accuracy and good generalization capability (Cristianini & Taylor, 2000). Recently, machine learning has been applied to perform condition monitoring, faults detection and classification. Kernel trick is one of the crucial tricks for machine learning. Its basic idea is to project the input data into a high-dimensional implicit feature space with a nonlinear mapping. The projected or output data is then analyzed so that the nonlinear relations of the input data can be described.

There are several contributions to the theoretical development of wavelet kernel reported in the literature such as reproducing the wavelet kernel (Rakotomamonjy & Canu, 2005), constructing the support wavelet network (Gao, Chen, & Shi, 2004), applying the wavelet support vector to regression (Zhang, Zhou, & Jiao, 2004), and using least square wavelet support vector (Yu & Cai, 2005). However, the application in faults detection and classification of machine is still uncommon. Therefore, the objectives of this study are to built and establish an intelligent fault detection and classification using wavelet support vector machine (W-SVM).

In this paper, a modified kernel trick using wavelet function is proposed and then induced in SVM theory. MCSA based on start-up transient current signal is used for faults detection and classification. Even though many researchers have performed fault detections of induction motors using MCSA, they did not employ intelligent technique to support their works (Benbouzid, 2000; Douglas & Pillay, 2004). Moreover, this paper also introduces the use of the principal component analysis (PCA) and kernel PCA (KPCA) for feature reduction and extraction. This method is employed to overcome the problem of higher-order dimensionality that tends to degrade the performance of the classifier (Yang, Han, & Yin, 2006). Finally, a new intelligent faults detection and classification method called W-SVM is presented. This method is used to induction motor for faults detection based on transient current signal.

2. Methods

2.1. Wavelet theory

Wavelet is known as a good tool for the analysis of non-stationary signals having transient behavior (Burrus, Gopinath, & Guo, 1998). The basis functions of a wavelet system are the scaling function $\phi(t)$ and the wavelet function $\psi(t)$ that can be derived from a single scaling or wavelet function by scaling and translation. A scaling function $\phi_{j,k}(t)$ scales and translates a function $\phi(t)$, where j is the $\log_2$ of the scale and $2^{-j}k$ represents the translation in time.

$$\phi_{j,k}(t) = 2^{j/2}\phi(2^j t - k) \tag{1}$$

The same way, in the case of wavelet function,

$$\psi_{j,k}(t) = 2^{j/2}\psi(2^j t - k) \tag{2}$$

The wavelet function $\psi(t)$ for the case where $j = k = 0$ is often referred to as the mother of wavelet.

2.2. Component analysis

2.2.1. Principal component analysis (PCA)

Given a set of centered input vectors $\mathbf{x}_t$ ($t = 1, \ldots, l$ and $\Sigma_{t=1}^{l}\mathbf{x}_t = 0$), each of which is of m dimension $\mathbf{x}_t = (x_t(1), x_t(2), \ldots, x_t(m))^{\mathrm{T}}$ usually $m < l$, PCA linearly transforms each vector $\mathbf{x}_t$ into a new one $\mathbf{s}_t$ by

$$\mathbf{s}_t = \mathbf{U}^{\mathrm{T}}\mathbf{x}_t \tag{3}$$

where $\mathbf{U}$ is the $m \times m$ orthogonal matrix whose ith column, $\mathbf{u}_i$ is the eigenvector of the sample covariance matrix

$$\mathbf{C} = \frac{1}{l}\sum_{t=1}^{l}\mathbf{x}_t\mathbf{x}_t^{\mathrm{T}} \tag{4}$$

In other words, PCA firstly solves the eigenvalue problem

$$\lambda_i\mathbf{u}_i = \mathbf{C}\mathbf{u}_i, \quad i = 1, \ldots, m \tag{5}$$

where λ_i is one of the eigenvalues of $\mathbf{C}$, $\mathbf{u}_i$ is the corresponding eigenvector. Based on the estimated $\mathbf{u}_i$, the components of $\mathbf{s}_t$ are then calculated as the orthogonal transformations of $\mathbf{x}_t$