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Singular value decomposition based feature extraction approaches for classifying faults of induction motors

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ABSTRACT

This paper proposes singular value decomposition (SVD)-based feature extraction methods for fault classification of an induction motor: a short-time energy (STE) plus SVD technique in the time-domain analysis, and a discrete cosine transform (DCT) plus SVD technique in the frequency-domain analysis. To early identify induction motor faults, the extracted features are utilized as the inputs of multi-layer support vector machines (MLSVMs). Since SVMs perform well with the radial basis function (RBF) kernel for appropriately categorizing the faults of the induction motor, it is important to explore the impact of the σ values for the RBF kernel, which affects the classification accuracy. Likewise, this paper quantitatively evaluates the classification accuracy with different numbers of features, because the number of features affects the classification accuracy. According to the experimental results, although SVD-based features are effective for a noiseless environment, the STE plus SVD feature extraction approach is more effective with and without sensor noise in terms of the classification accuracy than the DCT plus SVD feature extraction approach. To demonstrate the improved classification of the proposed approach for identifying faults of the induction motor, the proposed SVD based feature extraction approach is compared with other state-of-the art methods and yields higher classification accuracies for both noiseless and noisy environments than conventional approaches.

1. Introduction

Industrial processes need to be monitored in real time based on the input–output data observed during their operation. Abnormalities in an induction motor should be detected early in order to avoid costly breakdowns. The induction motor is widely used in industrial manufacturing, and its failures can result in significant economic losses. However, the growing scale of industrial processes involving induction motors has complicated the diagnosis and isolation of both electrical and mechanical faults of induction motors. Therefore, several approaches have been proposed for detecting faults in an induction motor system [1,2].

For the fault detection and classification of the induction motor, many researchers have mainly utilized current and voltage signals that can be easily measured. They have also used vibration signals for fault detection and classification since vibration signals are more effective at assessing a machine's status than current or voltage signals, even though vibration

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signals have non-deterministic and non-stationary characteristics [3]. Furthermore, vibration monitoring is the most reliable method of assessing the overall health of a rotor system [4]. For these reasons, this paper uses the vibration signals of the induction motor to classify faulty data from normal data.

Vibration signals are analyzed in the time, frequency, and time-frequency domains, and features are extracted using these analyses [5–7]. In this paper, we analyze the vibration signals of the induction motor in both the time and frequency domains and propose robust feature extraction methods to achieve high classification accuracy even in a noisy environment: one uses a short-time energy (STE) plus singular value decomposition (SVD) technique through the time-domain analysis, and another utilizes a discrete cosine transform (DCT) plus SVD technique with the frequency-domain analysis. We then use them as the inputs of the classifiers for the fault classification of the induction motor.

There are a number of classifier models for fault classification, such as analytical model-based methods and artificial intelligence-based methods (e.g., knowledge-based models and data-based models) [8–10]. Although analytical- and knowledge-based models are effective, they have low classification accuracy for the induction motor because they lack adaptability and are poorly suited to the random nature of vibration signals [10]. Some popular data-based models are used for detecting and classifying faults of the induction motor: neural networks, fuzzy systems, and support vector machines (SVM). This paper employs SVMs as classifiers since they provide better properties than other models, and they can also offer high classification performance with a limited training dataset. However, when SVMs are employed for classification, we need to select an effective kernel for the SVM. This paper utilizes the radial basis function (RBF) kernel, which performs better with SVMs. In this case, it is important to find both an optimal number of features and a value of standard deviation (σ) for the RBF, since these can strongly affect the classification accuracy. Thus, this paper measures the classification accuracy with different numbers of features and σ values for the RBF kernel in order to scrutinize the impacts of these factors on the fault classification.

The rest of this paper is organized as follows. Section 2 introduces related research, and Section 3 presents the data acquisition environment and a brief description of induction motor faults. In Section 4, the two proposed feature extraction methods are described, and Section 5 introduces multi-layer SVMs (MLSVMs) for fault classification of the induction motor. Section 6 shows the classification performance with different numbers of features and σ values for the radial basis function (RBF) kernel, as well as the performance improvement of the proposed approach, and Section 7 concludes this paper.

2. Related works

As mentioned in Section 1, vibration signals can be analyzed in the time, frequency, and time-frequency domains, and features are extracted through these analyses for identifying multiple faults in the induction motor [5–7,11,12]. Many researchers have utilized statistical values (e.g., mean, variance, root-mean-square, and kurtosis) and spectral powers using time and frequency analyses, respectively [5,11,12]. Moreover, statistical values using the short-time Fourier transform, discrete wavelet transform (DWT), and mel-frequency cepstral coefficients through a time-frequency analysis have been employed [5,6,11,13–15], and these features are suitable for most mechanical systems. The features (kurtosis, mean, and variance using DWT) in [11], for example, represent the characteristics of bearing faults well. As shown in Fig. 1(a) and (b), however, kurtosis- and mean-based features are less effective for classifying the faults of the induction motor due to irregular patterns with features, which lead to low classification accuracy. In addition, most of the extracted features are overlapped with the others, as depicted in Fig. 1(a) and (b), which results in difficulties in identifying the induction motor faults. To solve this problem, we propose efficient SVD-based feature extraction methods for distinguishing faults in the induction motor.

3. Faults of an induction motor

The experimental setup used in this study consists of pulleys, a belt, shaft, fan, and a 4-pole three phase induction motor, which operates at 0.5 kW, 220 V, and 3560 revolutions per minute, as shown in Fig. 2(a). Four induction motors were utilized to produce the data needed under full-load and steady-state conditions. One of the motors is healthy, and is considered as a baseline to discriminate from those with faults, including broken rotor bars, bowed rotor, bearing outer race

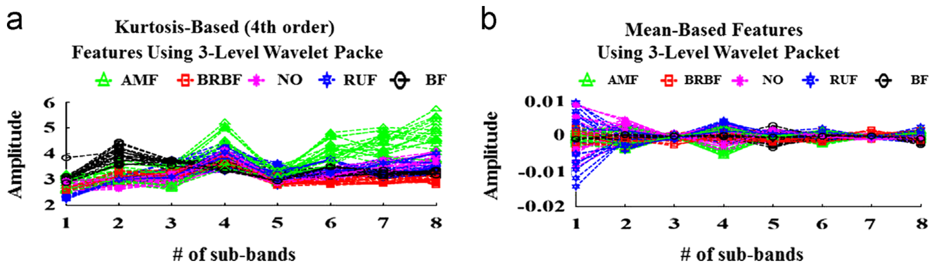

Fig. 1. Feature extraction results for classifying faults of the induction motor using the methods in [11]. (a) Fourth-order kurtosis-based features using a 3-level wavelet packet and (b) mean-based features using a 3-level wavelet packet.