Application of Multi-Wavelet Denoising and Support Vector Classifier in Induction Motor Fault Conditioning

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ABSTRACT
Induction motor fault conditioning is desirable to increase machine's performance and efficiency by avoiding consequential damages in near future of testing. Vibration signals' randomness prevents usage of any conventional methods for its analysis. Any non-conventional methods require extraction of different types of features and selection of features. This increases processing time of the whole conditioning system. In this paper, a different preprocessing technique, an extension to traditional approach, which uses basic statistical and frequency domain features, is used, hence reducing processing time. The preprocessing technique involves vibration signal denoising using wavelets and obtaining best trained data. Support vector machine classifier has been used for electrical and mechanical fault characterization. The effectiveness of the proposed method is proved through experimental results, and thus shown that a robust induction machine condition monitoring system has been produced

Keywords
wavelet denoising, SVM, piezoelectric accelerometer

1.INTRODUCTION
In production lines, fault diagnosis of induction motors are of great importance. Advantages of fault diagnosis are 1) reduce the cost of maintenance 2) reduce the risk of unexpected failures by allowing the early detection of destructive faults 3) smoothened working of machines. In condition monitoring, the information provided by condition monitoring systems assessing the machine's condition is used. On-line conditioning uses measurements taken while a machine is in operating on state or working.

Practical condition monitoring techniques for the three-phase induction motors are best dealt if both mechanical and electrical faults are considered. Vibration signals are directly related to a machine's working conditions, and are hence commonly used to detect machine faults. So in proposed method, we use vibration signals to built the fault conditioning system. Bearing faults and stator winding faults contribute a major portion to the induction motor failures. Though rotor faults appear less significant than bearing faults, most of the bearing failures are caused by shaft misalignment, rotor eccentricity, and other rotor related faults. Besides, rotor faults can also result in excess heat, decreased efficiency, reduced insulation life, and iron core damage. So detection of mechanical and electrical faults are equally important in any electrical motor.

There are two types of main features used in traditional approaches: statistical and the frequency domain. Both the features are dealt in this paper. The best available features of these two domains are extracted from the collected signals. The frequency domain features are more attractive because they give detailed information about the status of the machine whereas; the time domain features can give qualitative information about the machine condition. Generally, the machine vibration signal is composed of different kinds of vibration, and noise. If there is high level of vibrations and noise, inaccurate information about the machine faults is obtained. Signal processing techniques such as filtering, averaging, correlation, convolution, etc. can be used to discard effects of noise or vibrations

Recently, many developments towards fault diagnosis systems using classifiers based on artificial intelligence (Al) based techniques have produced good accuracy, but many of these modern fault diagnosis techniques have defects like cost of computational complexities, time taken for training data etc. Neural networks and fuzzy logic are widely used in the field of fault diagnostics and good results are obtained. Support Vector Machine, a machine learning technique is used in this paper. SVM is opted in this paper because accuracy of SVM does not depend on the number of features of classified entities.

In this paper an approach is used where cost of computational complexities, time taken for training data and accuracy all are optimum. Computational cost and training time can be made optimum by using traditional approach of statistical and frequency domain features extraction. Optimum accuracy is obtained by denoising signals before training data. Training dataset by denoising the signals with a single wavelet can increase accuracy to a better extent. To increase the accuracy dataset is trained by denoising different class of signals with different wavelets. The preprocessing technique is explained in detail, especially choosing different wavelets. The experimental observations and results are demonstrated with suitable graphs supporting it. This shows suitability of proposed technique in fault conditioning.

2. TRANSDUCER USED
Data collection and acquisition system for current and vibration signals is built as shown in (1). We collected signals using this system for data required to do analysis. To ensure that electrical

interference does not affect the vibration signal, a large signal is desirable, giving a high signal to noise ratio. The amplitude of vibration parameters also varies with rotational speed of the shaft. It is important consideration in transducer selection. As the speed of the shaft in the study is fairly high, acceleration will give high amplitude signal with high signal-to-noise ratio. Hence acceleration of vibration is chosen for fault diagnosis in present study. Accelerometer gives acceleration directly in the form of voltage signal.

Commonly used accelerometers are strain gauge type, capacitive type, and piezoelectric type. Here we use piezoelectric type since it has high natural frequency. For frequency ratios, the ratio between the vibrating member and the natural frequency of the accelerometer greater than 0.4, the response was found to be non-linear for other type of accelerometers; thus piezoelectric type is preferred.

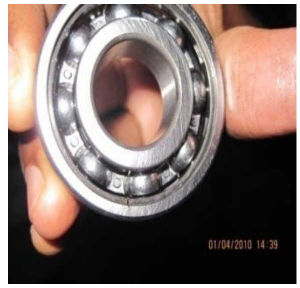
Advantages of piezoelectric accelerometer are:

- Instrument is small and weightless
- Natural frequency of the instrument is very high so they can be used for vibration applications which produce sudden change in the frequency spectrum
- Linear throughout the range.
- Low sensitivity to outer distortions including temperature fluctuations
  Accelerometer available in our lab is BRUEL &KJAER piezoelectric accelerometer
  - Temperature range: – 74° to + 250°C.
  - Acceleration range: 20 ms–2 to 1000 kms–2.

Figure 1.BRUEL &KJAER piezoelectric

3. FAULTS DEALT

The most prevalent faults are bearing fault, Stator or armature faults, broken rotor bar faults and eccentricity related faults. Thus the majority of faults occur in the bearing, stator and rotor part. All the faults dealt are induced and acceleration of vibration signals is noted with piezoelectric accelerometer under no load conditions.
Faults dealt with are:
1) Broken bars (rotor fault)
2) Motor running in two phase (stator fault)
3) Open circuited windings (stator fault)
4) Outer race (bearing fault)
5) Inner race (bearing fault)
Good condition is also taken as a class in processing technique



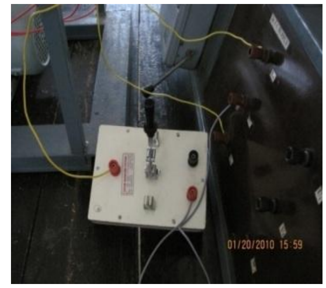


Figure 2: Bearing fault with outer race **Motor running in two phase**

4. PREPROCESSING TECHNIQUE

There are six classes of signals which include five faulty conditions and good working condition of induction motor. Each class has 200 sample signals for training. To get the optimum training set, following steps are followed:

1) First system is trained with sample signals which are not denoised.

2) Online testing is done by collecting 100 sample signals and accuracy is noted.

3) Same procedure is repeated for signals after denoising sample signals (7) (8) (9) with different types of wavelets and different levels of decomposition.

4) For each class, training set which gives the best accuracy is noted.

5) Now build a new set where signals are denoised with wavelet and level which gives best accuracy for that particular class of signals in testing which is mentioned in first 3 steps.

6) Now online signals are tested to get better accuracy

5. WAVELET DENOISING

Steps in wavelet denoising are:-
1) Decomposition- Wavelets such as symlet12 and db10 are selected. Levels of decomposition for the signal are three and six for symlet12 wavelet and six for db10 wavelet

2) Thresholding- To discard detail co-efficient, select a threshold in each level from 1 to the level selected and apply either hard or soft thresholding. In this paper, soft thresholding is applied.

3) Reconstruction-Compute the signal with approximate coefficients and detailed coefficients obtained after soft thresholding

6. FEATURE EXTRACTION

Feature extraction of the signal is a critical initial step in any monitoring and fault diagnosis system. In this paper, the features of the signals are extracted from the time domain, frequency domain (1).

Table 1: Number of features

SPACE	NO OF FEATURES
Time domain	11
Frequency domain	5

Features extracted in:

Time domain: Mean, Standard deviation, covariance, Skewness, Kurtosis, minimum, maximum, range, entropy, variance, root mean square and mean square.

Frequency domain: Center frequency, Root mean square frequency, standard deviation frequency and mean frequency. Features are obtained from FFT spectrum

7. FEATURE CLASSIFICATION

Support vector machine is used to build a classifier. A Support Vector Machine (SVM) performs classification by constructing N-dimensional hyper planes that optimally separates the data into many categories (2) (3) (5). SVM finds the hyper plane placing the largest possible number of points of the same class on same side, while maximizing the distance of either class from the hyper plane. When SVM cannot draw a linear separating line between classes, rather than fitting nonlinear curves to the data, SVM handles this by using a *kernel function* to map the data into a different space where a hyper plane can be used to do the separation

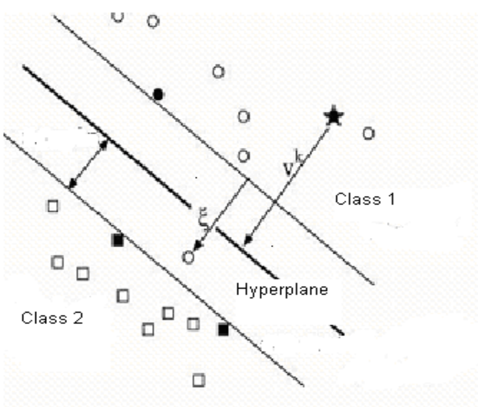


Fig 3: Binary classifier

Though SVMs are binary classifiers, for the fault detection in induction motor we are in need of multi-class SVM. Such multi-class SVM is obtained by decomposing the multi-class problem into several number of binary class problems. Then classifiers are trained to solve the problems assigned to each binary SVM.

. Here, we are using one against others approach. In this method, one class is compared with all other classes in multi- class structure. Classification of new instances using one-versus-all method is done, in which the classifier with the highest output function assigns the class. Here we are using mat svm inter toolbox to design the classifier

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8. EXPERIMENTAL DETAILS AND RESULTS

1) As described in the pre-processing technique, first training is done with vibration signals which contain noise and a classifier is obtained. Results obtained after testing various classes of signals are

Table 2: Data without denoising

WITHOUT DENOISING	FAULT	ACCURACY
VIBRATION	Good	90
	Inner race	36
	Outer race	100
	Open	83
	2phase	96
	Rotor	55

2) Now signals are denoised using Level3 symlet12 wavelet and then training is done and classifier is obtained. Results obtained after testing

Table 3: Data denoised with Level 3 db10

Level 3 sym12 WITH DENOISING	FAULT	ACCURACY
VIBRATION	Good	81
	Inner race	34
	Outer race	94
	Open	79
	2phase	94
	Rotor	63

3) Signals are denoised using Level 6 db10 and then training is done. Results obtained after testing

Table 4: Data denoised with Level 6 db10

Level 6 db 10 WITH DENOISING	**FAULT**	**ACCURACY**
VIBRATION	Good	84
	Inner race	87
	Outer race	96
	Open	96
	2phase	86
	Rotor	75

4) Signals are denoised using Level 6 symlet12 and then training is done. Results obtained are

Table 5: Data denoised with Level 6 symlet12

Level 6 Symlet 12 WITH DENOISING	**FAULT**	**ACCURACY**
VIBRATION	Good	83
	Inner race	90
	Outer race	100
	Open	89
	phase	86
	Rotor	54

Now from the above accuracy table, for each class of signals, training technique which gives the best accuracy is determined. It is clear that denoising helps only some class of signals. This can be seen from graphs below

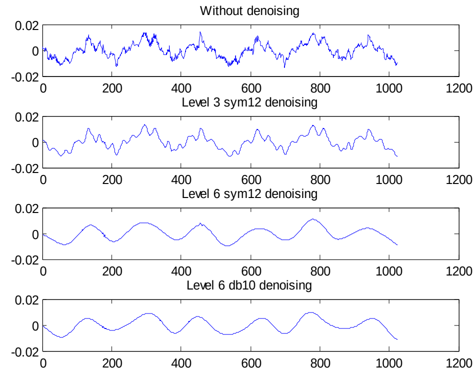

Fig 4: Inner race fault signal

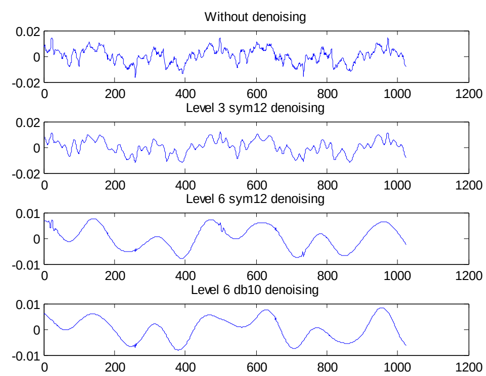

Fig 5: Open circuit fault signal

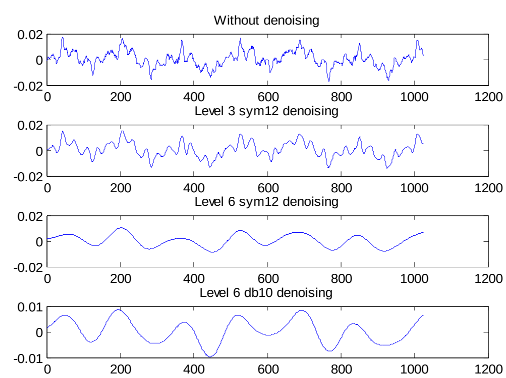

Fig 6: Rotor fault signal

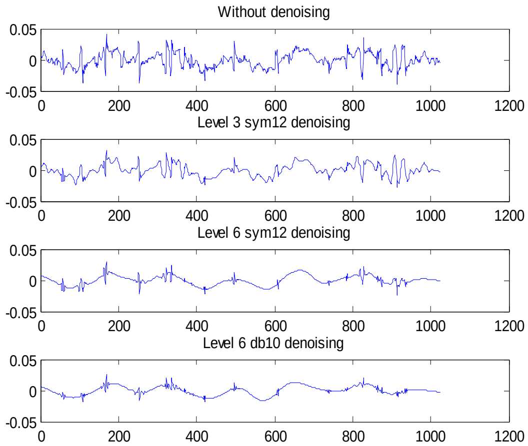

Fig 7: Outer race fault signal

Thus observations can be tabulated as

Table 6: Best wavelet for each fault

FAULT	**CONDITION OF TRAINING IN WHICH THE BEST ACCURACY OBTAINED**
Good	Without denoising
Inner race	Denoised with Level 6 Sym12 wavelet
Outer race	Denoised with Level 6 Sym12 wavelet /without denoising
Open	Denoised with Level 6 db10 wavelet
2phase	Without denoising
Rotor	Denoised with Level 6 Symlet12 wavelet

Now, to get better accuracy, first each class of signals are obtained as given in above tabular column, features are extracted; these features are used for training dataset. Thus there are two possible combinations of training are possible. Results obtained after testing are

Table 7: Wavelet combination group1

FIRST COMBINATION	**FAULT**	**ACCURACY**
Without denoising	Good	87
Level 6 Symlet12	Inner race	88
Level 6 Symlet12	Outer race	93
Level 6 db10	Open	95
Without denoising	2phase	97
Level 6 Symlet12	Rotor	96

Table 8: Wavelet combination group2

SECOND COMBINATION	**FAULT**	**ACCURACY**
Without denoising	Good	97
Level 6 Symlet12	Inner race	88
Without denoising	Outer race	100
Level 6 db10	Open	97
Without denoising	2phase	97
Level 6 Symlet12	Rotor	98

Thus it is observed that when training is done according to second combination mentioned above, better results are obtained. Time for processing is 0.6 sec.

9. CONCLUSION

In this paper, machine fault diagnosis of an induction motor using vibration signals is discussed. Inner race fault, Outer race fault, Open circuit, two phase and Rotor fault are five faults dealt. Fault signal is denoised using wavelet and statistical and frequency domain features are extracted and faults using support vector machine. Our results show that the combination of wavelet denoising and SVM of vibration signal (3) used to detect faults in bike engine. Advantage is that processing is easy and consume less time when compared to other techniques

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