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The Application of Neural Network to Electrical Motors' Sound Recognition System

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Abstract: In this study, neuro based intelligent methods for electrical motors' sound recognition system are proposed. The sound signals were used to recognize the loads speed and fault diagnosis of the motors. The sound signals were processed by two separate methods, the FFT and Discrete Wavelet Transform (DWT). The results of both methods were compared to obtain the most suitable of them.

Key words: Electrical motors, signals, sound recognition system, DWT, FFT, Iraq

INTRODUCTION

When some failure occurs in an electrical motor, diagnosis of the system is to be performed. Also, the continuous monitoring of the motors by operator is tedious and in most times requires special equipments to be monitored continuously. Therefore, using the proposed system will be very useful in monitoring and diagnosis the motors remotely. In this study, the sound signals of the motor were taken for different operating conditions, to be used by the neural network to recognize the fault, the loads and speed of the motors. Less attention was taken by researchers to use the sound signals of the electrical motors in fault diagnosis or recognizing the different operating conditions of the motor, this is due to the noisy environment of the work place of the motors. Dufaux *et al*. (2000) proposed a good method to collect the motors sound signals in a noisy environment.

Some researchers worked on the fault diagnosis of electrical motors (Kim *et al*., 2003; Ayaz *et al*., 2003) or of electro-mechanical system (Torigoe *et al*., 2005) but very few used the sound signal as an input to the recognition system (Tsao and Wu, 1999).

Also, the processing of the sound signal was done mainly by FFT Method [b] with no study of other methods for the processing stage of the recognition system. Here, the DWT Method will be compared by the FFT Method of processing to study the suitability of either of them for the use in this field.

MATERIALS AND METHODS

Motor sound samples: The motor used here is a 3-phase induction motor at 1.1 kW power. This motor was subjected to various tests for:

- Various load rates
- Various speed
- Different faults (here two faults were tested, the first is the unbalanced load, the second is the failure of one of the 3-phases)

The sound signals were recorded using a microphone (50 H to 18 KHz) frequency response and the database obtained contained the sound samples of different operation conditions of the motor according to the tests mentioned before. The time period for each sound signal sample was 40 sec. The 1st 20 sec was used for ANN training and the 2nd 20 sec for testing the ANN. The sampling frequency used to convert the second signal into digital is 44100 Hz.

Feature extraction: Here, two methods were used to have the features of the sound signal from the samples obtained for various working conditions. The first method was the FFT.

FFT: The following steps were followed to obtain the FFT factors for the second samples.

Dividing each 1 sec time period into (F) frames of 4096 sample and 100 ms time period:

$$(X_{f}, {}_{f} = 1, 2, ...F) \quad (1)$$

Where:

X_f = Represents a given frame
f = Frame index
F = No. of frames

Each frame is interconnected with the adjacent frame by 512 sample. Hence, frames will be obtained for each 100 m sec frame. Using a hamming window for each

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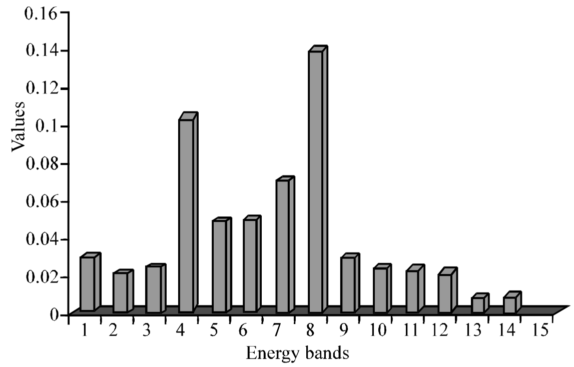

Fig. 1: The average of the power spectrum of 1 sec

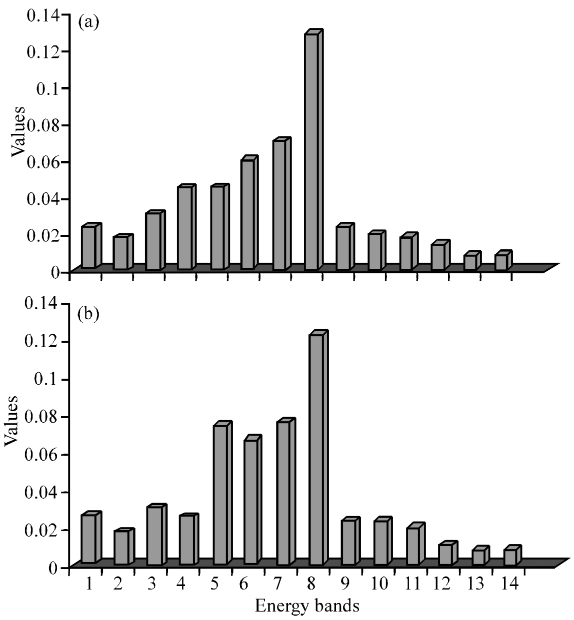

Fig. 2: a, b) Shows a sample of variation of power spectrum for two different loads

$$h_i = 0.54 - 0.46\cos(2\pi\frac{i}{4096}) \quad (2)$$
$$i = 0,1,2,.......,4096$$

$$X_{fi} = X_{fi}\,h_i \quad (3)$$
$$i = 0,1,2,....4096$$

frame to reduce the Gibbs effect (Ludeman, 1986). The application of FFT for each frame. The power spectrum vector is taken only as the phase vector is of no use in sound recognition. Normalization of each frame each spectrum is divided into 14 band (the No. 14 is chosen as the DWT will be represented by (13) features). Then the average of each band for each 1 sec time period is taken hence, a (14) parameter vector is obtained. Figure 1 shows the average of the power spectrum of 1 sec. Figure 2a, b shows the variation of power spectrum for two different loads.

Discrete Wavelet Transform (DWT): The processing steps followed to obtain the DWT feature parameters were each 1 sec time period is divided into (F) frames of 40 samples and 100 m sec time period. The discrete wavelet transform is computed for each frame for 12 level as follows: Here, the sound signal is analyzed using the discrete wavelet transform into sets of wavelet parameters (detail parameters $D_J(i)$ and approximation parameters $A_M(i)$) then the detail parameters are compressed in each level and the approximation parameters are compressed in the last level only. That is so to have a set of the detail parameters represented by only one parameter in each level. The same process is done to the approximation parameters to be represented by only one parameter. This is done by taking the root mean square to compute the energy in each level (ED_J) for the detail parameters and energy for the approximated parameters in the last level (EA_M). Then the feature vector will be:

$$F = [EA_M\ ED_M\ ED_{M-1}\ ED_{M-2}..........ED_1]^T \quad (4)$$

$$EA_M = \sqrt{1/P_{MA} \sum [A_M(i)]^2} \quad (5)$$

$$ED_j = \sqrt{1/P_{JP} \sum [D_J(i)]^2} \quad (6)$$

Then each frame will be represented by a (13) parameter vector. Each second time period will be represented by a matrix of 13*10. Each frame vector is normalized.

The average of energy feature vector in one second is computed. This is to reduce the effect of spectrum change due to the vibration. Finally a (13) parameter vector is obtained.

RESULTS AND DISCUSSION

The application of ANN: For the classification step, a back propagation trained Artificial Neural Network (ANN) was used different ANN were designed for the classification process one for each of the samples of the sound signals, i.e., the sound samples of the motor for different loads, different speeds and different faults. The number of layers of the ANN were chosen to be three, the input layer, one hidden layer and the output layer. The number of inputs to the input layer depends on the number of parameters in the feature vector which is (14) in the case of FFT vector and (13) in the case of DWT vector. For the output layer, the numbers of outputs depends mainly on the numbers of classifications required, i.e., numbers of loads to be classified, number of speeds and faults to be recognized. The obtained feature vectors of FFT and DWT were applied to these ANNS and the results were obtained.

Table 1: Percentage of the correctly recognized samples

Sound types	Recognition (%)
Different loads	90.0
Different speeds	84.0
Faults	91.6

Table 2: Applying the DWT vector using DB4

Sound types	Recognition (%)
Different loads	96.5
Different speeds	97.5
Faults	100.0

Table 3: Recognition percentage for different loads

Signal to noise ratio/dB	FFT recognition (%)	DWT recognition (%)
50	95	98
20	93	97
15	90	91
10	78	80
5	60	52
0	45	37
-5	30	32
-10	20	25
-20	18	20

Table 4: Recognition percentage for different speeds

Signal to noise ratio/dB	FFT recognition (%)	DWT recognition (%)
50	95	95.5
25	95	96.0
20	90	93.0
15	82	88.5
10	72	82.5
5	58	75.0
0	47	64.0
-5	32	45.5
-10	20	37.5
-15	10	34.0

Table 5: Recognition percentage for different faults

Signal to noise ratio/dB	FFT recognition (%)	DWT recognition (%)
50	95	97.7
25	95	97.7
20	95	96.6
15	93	92.7
10	90	78.7
5	65	72.7
0	50	47.7
-5	40	28.3
-10	35	26.6
-15	28	23.3
-20	20	22.7

The FFT: The FFT vector of the motor signals of different loads, different speeds and different faults were applied to the ANN. Table 1 shows the percentage of the correctly recognized samples.

The DWT: The DWT was applied with different filters and it was found by trial and error that the application of DB4 filter gives the best overall recognition results. Table 2 shows the results applying the DWT vector using DB4 to the ANN. Then multi levels of white noise were added to the sound signals to study the applicability of the proposed method when applied in a noisy environment. Table 3-5 show the percent of recognition versus the signal to noise ratio.

CONCLUSION

In this study, the application of ANN in the recognition process of electrical motor sound showed to be very suitable in recognizing the sounds, speeds and motor functions. For feature extraction the results obtained using DWT gave excellent recognition percentage compared to FFT. Both methods gave applicable results but DWT results were much higher. DWT showed to be useful even with the addition of noise. This means that the use of the designed system can be of great benefits even in a noisy environment, like factories.

The only restriction here is to put the microphones used to record the motor sounds in the suitable place to reduce as possible the noise. The designed system can be very useful in telemonitoring electrical motors working in distant unreachable places. This system can be used to monitor motor malfunctions, without the need of human interaction.

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