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## Faults detection of gearbox of MF285 tractor based on Wavelet Packet Transform and ANFIS

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### ABSTRACT

In this paper, an approach based on Wavelet packet transport, principal component analysis is presented for detection of fault diagnosis of gearbox of MF285 tractor. The vibration signal acquired from the experimental set up has been used to diagnose the condition. An acceleration sensor is used to pick up the vibrational signals by experimental set up. After acquisition vibrations data, processing performs by the wavelet packet transform (WPT). Three types of conditions included health gear, and gear with tooth breakage and gear with face wear obtained from the database. The proposed approach is applied to fault diagnosis of gearbox of MF285 tractor, and testing results show that the proposed model can reliably predict different fault categories and severities.

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## INTRODUCTION

The gearbox is one of the most important parts of MF 285 tractor. This gears use to transfer power from the engine to the drive wheels and power take off (PTO) of the tractor. This gearbox is used for increasing torque and reduction speed or alters speed and torque; it also can reverse motion and stop the wheels moving, without turning off engine or pressing clutch pedal.

While defects occur in the gearbox the time of agricultural operations may be reacted. Therefore it is important to identify these faults that even may be being able to cause to stop the whole system (Loutridis, 2008). Fault diagnosis based on vibration is one of the most traditional methods because it is easy to measure (Halima *et al.*, 2008; Jafarizadeh., 2008., Zuo, *et al.*, 2005).

There are many methods to analysis of vibration signals .Wavelet Transform is popular and applicatory for vibration analyses. Furthermore, the Wavelet Packet Transform has been used in research successfully.WPT and Hilbert transform can be an effective method for fault diagnosis in many machinery like rolling element bearings (Fan & Zuo, 2006; Lei *et al.*, 2009; Feng & Schlindwein, 2009; Rafiee, 2007; He *et al.*, 2007; Zhou *et al.*, 2011; Yan & Gao, 2005).

Also by using Wavelet Packet Analysis (WPA) and Kolmogorov-Smirnov (KS) vibration signals have been analyzed (Chen *et al.*, 2008). In such case the Wavelet Packet Analysis applied in two levels. The reconstructed denoised vibration signal with improved signal-to-noise ratio (SNR) and then the kurtosis of the de-noised signal computed and the KS test applied to the kurtosis statistical probability distribution (SPD) for classification of different seven conditions of piston faults in hydraulic pump water (Chen *et al.*, 2008).

Combination of WPT with neural networks today's is one of the interest fields for many researchers. Application of neural networks can help to classify of faults and also find a feature selection of signals and an acceptable model in fault diagnosis (Wu & Hsu, 2009; Wu & Liu, 2009; Pan, Y.; Chen & Li, 2010; Lou, & Loparo, 2004; Ye, 2006; Ebrahimi, 2013; Ebrahimi, 2013).

In this work fault detection of a gearbox of MF285 tractors with vibration signals will be studied. After apply wavelet packet transfer on vibration signals in different conditions of fault, results of this method as one of signal processing methods will be compared with other popular methods like Fourier transform(FT) and wavelet Transform(WT).

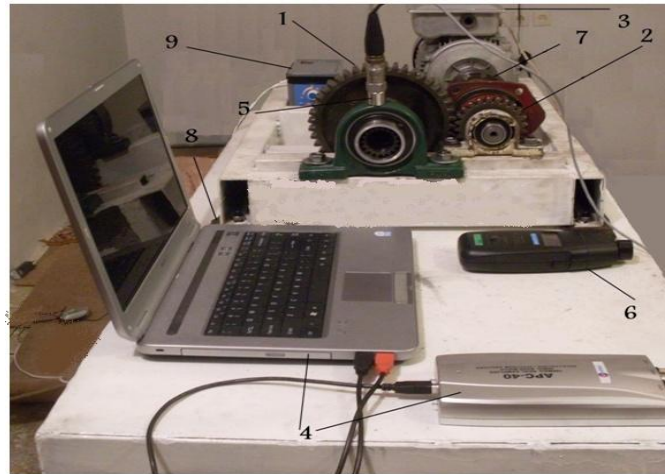
### Experimental Set up:

The gear's number one in MF285 Tractor is most affect fault rather than other gear's number. The gear's number one is stuck of the gear clutch main axle head. The gear's nobler one of MF 285 tractor has 44 gears. In

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this work, three kind of conditions fault included health gear; gear with tooth breakage and gear with face wear for studding fault detection have been consider.

Figure 1 shows the experimental set up for this study. The model of gear No1 mounted on this set up. Two long strips of rubber material used for vibration absorbing. A single phase electric motor - model YCA90S-2- connected to the input shaft in order to supply the rotational motion of the gears. An acceleration sensor is used to pick up the vibration signals produced by experimental set up. A piezoelectric accelerometer used for this set up was - model VMI Ltd, VMI102 Sweden- with magnetic holder. This sensor set on the bearing in radial position. The analyzer device –model APC- 40, APC Ltd – applied for transfer analog output to digital data. This analyzer device attached to laptop USP port through connection cable. In other to data acquisition to be taken in terms of the speed certain for different condition, the tachometer –model DT-2234B - used to gauge the speed of shaft. To provide different speed, the dimmer switch make voltage rise and fall to electric motor make different speeds.



**Fig. 1:** Experimental Set Up

Devices used as experimental set up showed in figure 1 are listed follow:

- 1 - gear, gear shafts
- 2 - small gears to transfer power to the main gear.
- 3 - Single phase Electric motor with power 750 W
- 4 - The system captures data APC-40 and laptop
- 5 - Accelerometer sensor VMI-102
- 6 - Model DT-2234B optical telemeter
- 7 - coupling to connect the input and output shaft gear
- 8 - Vibration absorbing rubber base
- 9 - Industrial dimmer to a different point in the input coupling and shaft of the motor.

In this study, the data were taken in three conditions, good gear, gear with tooth breakage and gear with face wear and in the three rotation speed of 1000, 1500 and 2000 rpm.

#### *Wavelet packet transform:*

The wavelet transform has been employed for signal and image compression feature extraction, classification algorithms, telecommunication applications, numerical mathematics, and many other fields. A wavelet transform can be used to process the signal in the time domain and frequency domain. Well as the ability to be demonstrate transient and non-stationary signals (Prabhakar *et al*, 2002). Continuous wavelet transform is defined by following the relationship (Wu & Hsu, 2009).

$$CWT(a, b) = \frac{1}{\sqrt{|a|}} \int_{-\infty}^{\infty} X(t) \psi^* \left( \frac{t-b}{a} \right) dt \quad (\text{Loutridis, 2008})$$

In this formula, a is the scale which is the inverse ratio to frequency, b is the translation parameter,  $\psi$  is the “mother” wavelet and  $\psi^*$  is the complex numbers whose real parts are identical and whose imaginary parts differ only in sign of  $\psi$ . Though, the continuous wavelet transform needs very of the procedure of calculating to find the scale at every analysis signal (22). The discrete wavelet transform is a discrete make of the continuous

wavelet transform. It adopts the scale and translation to make a reduction in calculation time (14). The discrete wavelet transform can be showed as following formula.

$$DWT(a, b) = \frac{1}{\sqrt{2^i}} \int_{-\infty}^{\infty} X(t) \psi^* \left( \frac{t-2^i K}{2^i} \right) dt \quad (\text{Halima } et al., 2008)$$

Where  $a$  and  $b$  are  $2^j$  and  $2^j k$ , respectively. In discrete wavelet transform, the signals are decomposed into a structure of data having several levels Set into a specific format in a branching structure of detail and approximations at levels (Rafiee *et al.*, 2009). The DWT can be represented with filters concept as a complementary filters. The complementary filters include of a high-pass filter and a low-pass filter, which is obtained high frequency (Details ( $D_j$ )) and low frequency (Approximations ( $A_j$ )) wavelet coefficients, respectively as follow (Wu & Liu, 2009).

$$f(t) = \sum_{i=1}^j D_i(t) + A_i(t) \quad (\text{Jafarizadeh } et al., 2008)$$

Where  $D_i(t)$  is the wavelet detail and  $A_j(t)$  is the wavelet approximation at the  $j$ th level as shown in figure 2.

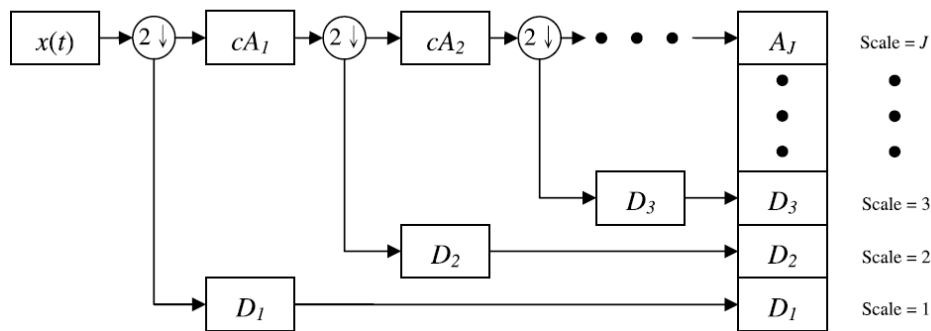


Fig. 2: Discrete wavelet transport decomposition

In the wavelet packet transform, signal at each level decompose into approximation and detail signal. When, the wavelet packet transport is applied on signal, at first, the signal is divided into two parts called packets. Low frequency is closed so the left side and the right package include high frequencies. In the secondly level, each packet is divided into two packets. The decomposition is performed in the other level. The application of Wavelet Packet Transform is shown in Figure3.

The WPT can be represented as:

$$W_{j,k}^n(t) = 2^{j/2} W(2^j t - k), \quad j, k \in \mathbb{Z} \quad (\text{Zuo } et al., 2005)$$

Where, the  $j$  and  $k$  are the scale and translation.

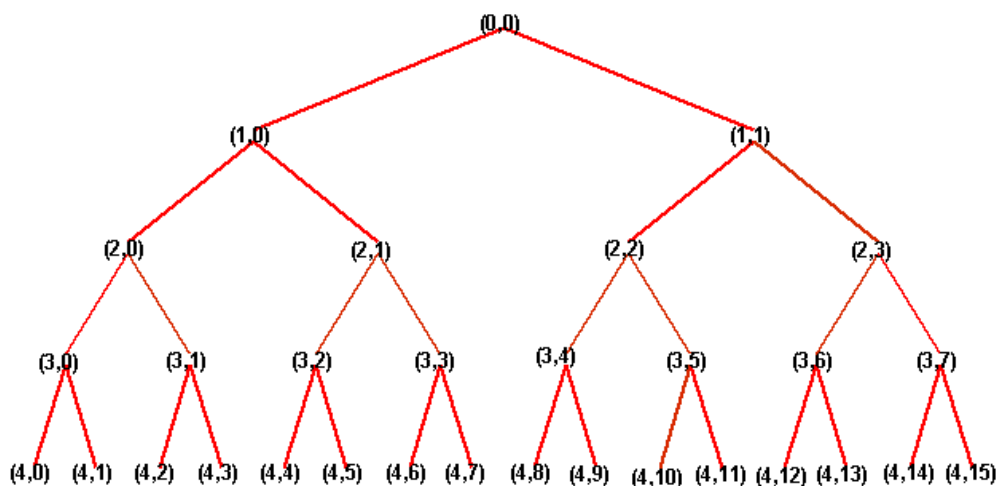


Fig. 3: WPT decomposition tree

The  $n$  is defined as an oscillation parameter. The first two wavelet packets are the scaling function  $\phi(t)$  and mother wavelet functions  $\psi(t)$ :

$$W_{0,0}^0(t) = \varphi(t) = \sqrt{2} \sum_k h(k) \varphi(2t - k) \quad (\text{Fan \& Zuo, 2006})$$

$$W_{0,0}^1(t) = \psi(t) = \sqrt{2} \sum_k g(k) \varphi(2t - k) \quad (\text{Lei \& He, 2009})$$

When  $n = 2; 3; \dots$  the function can be defined by the following relationships:

$$W_{0,0}^{2n}(t) = \sqrt{2} \sum_k h(k) W_{1,k}^n(2t - k) \quad (\text{Feng \& Schlindwein, 2009})$$

$$W_{0,0}^{2n+1}(t) = \sqrt{2} \sum_k g(k) W_{1,k}^n(2t - k) \quad (\text{Rafiee et al., 2007})$$

Where  $h(k)$  and  $g(k)$  are the quadrature mirror filter associated with the predefined scaling function and mother wavelet function. The wavelet packet coefficients,  $W_{1,k}^n$  are calculated as:

$$W_{j,k}^n = \langle f(t), W_{j,k}^n \rangle = \int f(t) W_{j,k}^n dt \quad (\text{Rafiee et al., 2007})$$

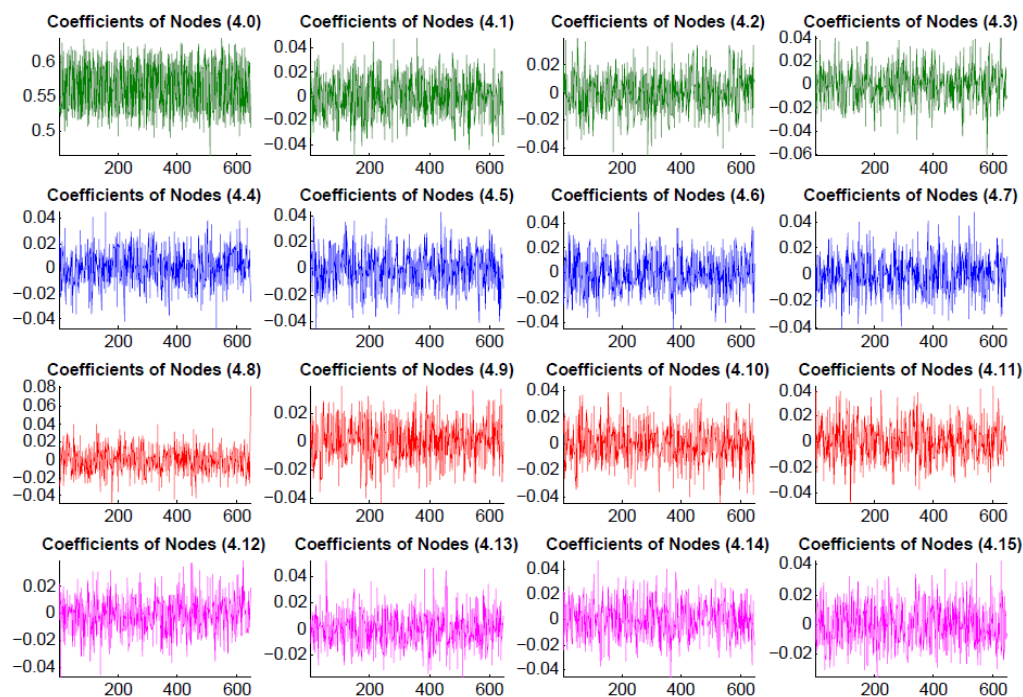
The frequency interval of each node is given by

$$\left[ \frac{n-1}{2^{j+1}} S_f, \frac{n-1}{2^{j+1}} S_f \right]. \quad (\text{He et al, 2007})$$

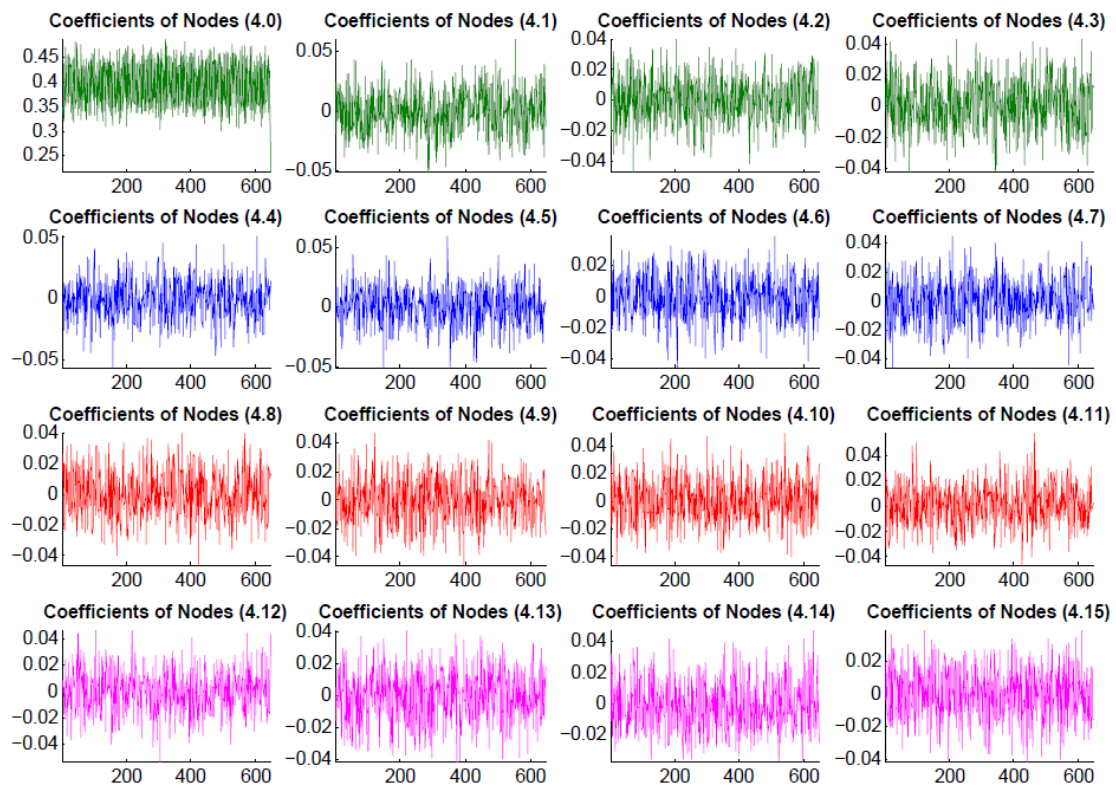
, where  $S_f$  is the sampling frequency,  $j$  the scale index and  $n$  the number of levels  $n=1, 2, \dots, 16$ . (23)., the plots of wavelet packet transforms (WPT) decomposition by DB4 family in level 4 for normal gear signal, wear gear signal, break signal are shown, in figures 4,5 and 6.

#### Feature extraction:

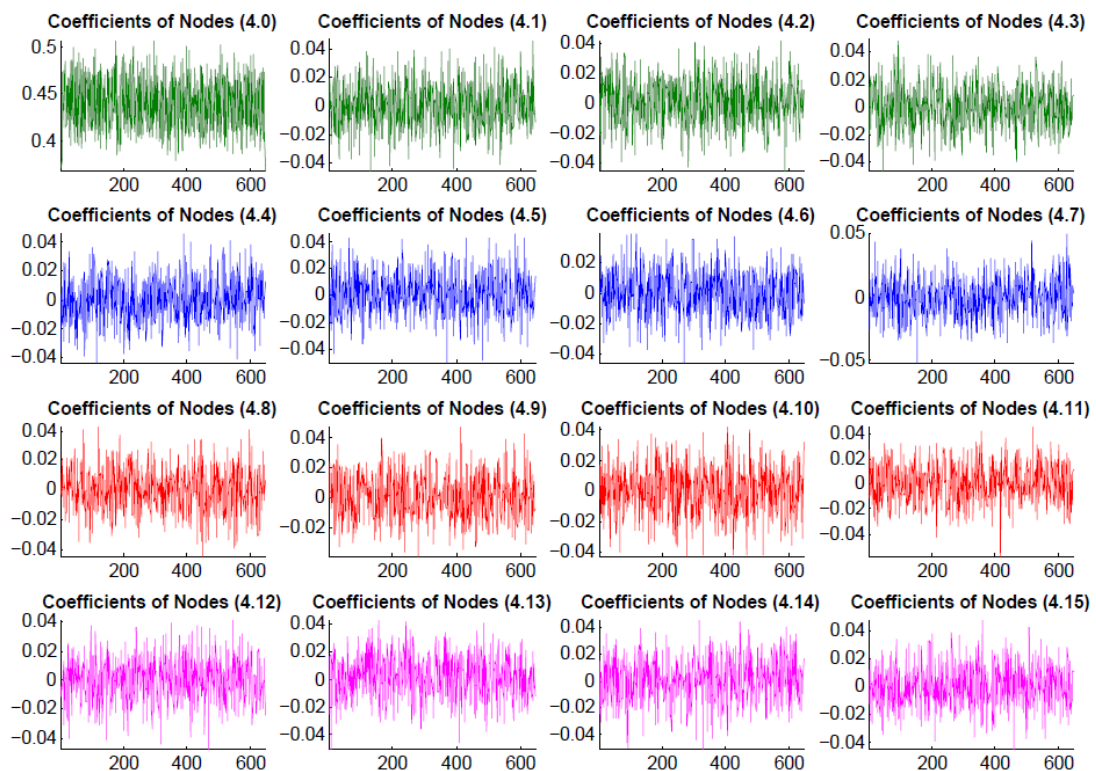
In this work, for extracting features, the vibration signal is gained from experimental set up, then so that the data acquisitionist did in 1000, 1500 and 2000 rpm speed. In all three conditions the speed of normal gear, wear gear tooth and fracture gear teeth were examined. Each stage has 130 samples and the sampling was performed for 4 seconds. Then the wavelet packet transform was obtained from the original signals. This transform was done by mother wavelets Db4, Db9& Db20 at four levels. The standard deviation was calculated at wavelet packet transform coefficient of the fourth level. So, the 16 standard deviation were obtained for each of 130 period of data record for different condition. Then, in this step PCA was used to reduce the attributes. By using PCA obtain two components that present 80.11, 79.41 and 74.62 percent from the variations in data set for mother wavelets Db4, Db9& Db20, respectively. These components variations are shown in Table 1, also, the components coefficients presented in table 2 so that the two components are linear combination of these variables. For component related to Db9 are pretermited variables 1&2 and for component related to Db20 is a pretermited variable 1 because this variables don't show the variations.



**Fig. 4:** Wavelet packet transforms (WPT) decomposition in level 4 for normal gear signal



**Fig. 5:** Wavelet packet transforms (WPT) decomposition in level 4 for wear gear signal



**Fig. 6:** Wavelet packet transforms (WPT) decomposition in level 4 for break tooth signal

**Table 1:** Component Matrix

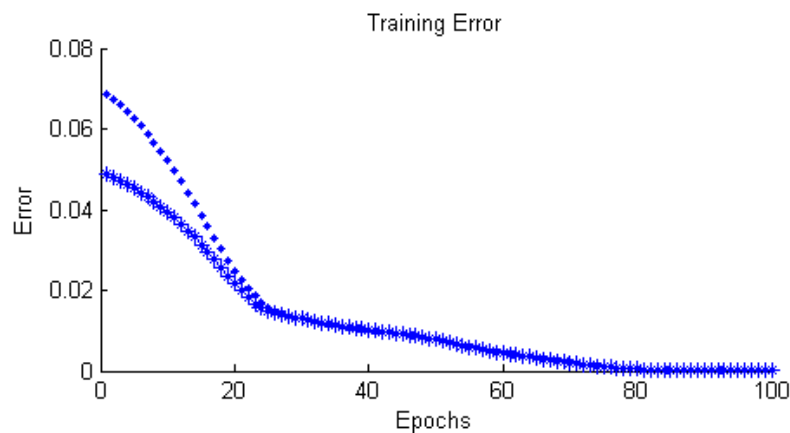
	Component related to Db4		Component related to Db9		Component related to Db20	
	1	2	1	2	1	2
1	-.114	.978	-	-	-	-
2	.084	.981	-	-	.314	.735
3	.787	.152	.785	.378	.260	.863
4	.830	.189	.300	.853	.744	.341
5	.887	-.069	.602	.690	.883	.254
6	.925	-.006	.659	.590	.739	.452
7	.865	.039	.877	.280	.457	.757
8	.877	-.132	.509	.740	.633	.629
9	.876	-.027	.661	.576	.656	.513
10	.890	-.115	.660	.574	.623	.577
11	.872	-.034	.602	.643	.788	.389
12	.835	-.037	.578	.651	.740	.450
13	.915	-.004	.394	.833	.582	.669
14	.922	.011	.756	.523	.612	.638
15	.895	.014	.676	.548	.626	.546
16	.893	-.102	.674	.543	.576	.609

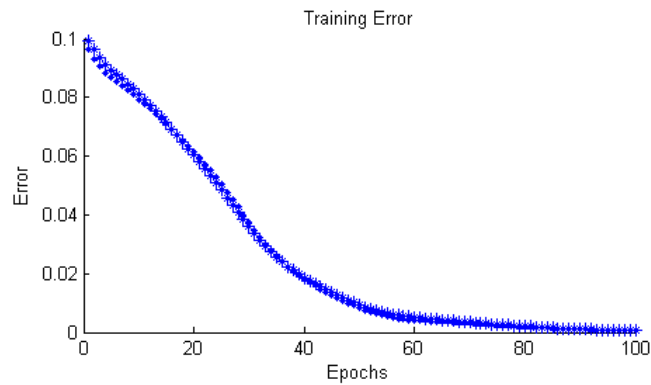
**Table 2:** Component Score Coefficient Matrix

	Component related to Db4		Component related to Db9		Component related to Db20	
	1	2	1	2	1	2
1	-.003	.482	-	-	-	-
2	.015	.485	-	-	-.247	.377
3	.074	.081	.375	-.275	-.361	.509
4	.078	.100	-.418	.544	.275	-.193
5	.082	-.028	-.030	.156	.419	-.345
6	.086	.004	.098	.019	.204	-.104
7	.081	.026	.532	-.439	-.167	.306
8	.080	-.059	-.149	.275	.026	.098
9	.081	-.007	.111	.004	.113	-.006
10	.082	-.050	.112	.003	.052	.064
11	.081	-.010	.008	.112	.274	-.182
12	.077	-.012	-.019	.139	.206	-.106
13	.085	.005	-.322	.451	-.032	.161
14	.086	.012	.236	-.120	.006	.119
15	.083	.013	.147	-.034	.072	.039
16	.082	-.044	.149	-.037	.001	.118

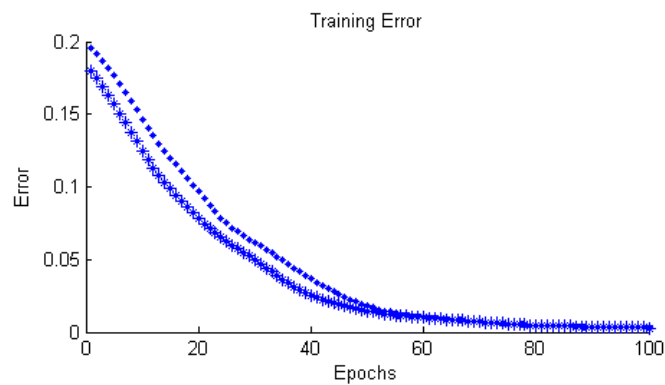
#### Apply ANFIS to classification of faults:

In this study ANFIS was used to faults classification predicts. System verification and validation were carried out by the checking data. So that 70% from of dataset were used to training stages and the 30% were used to checking stages. Training data and checking data sets were chosen randomly. Training data may be coinciding on model but the checking data don't coincide on system while, the procedure of train doesn't perform properly. The training error related to Db4, Db9 and Db20 is shown in Figures 7, 8 and 9 respectively. These figures show the checking error as ♦♦ on the top. The training error appears as \*\* on the bottom. The checking error and the training error appears low to an Epoch 100.

**Fig. 7:** Training error related to Db4

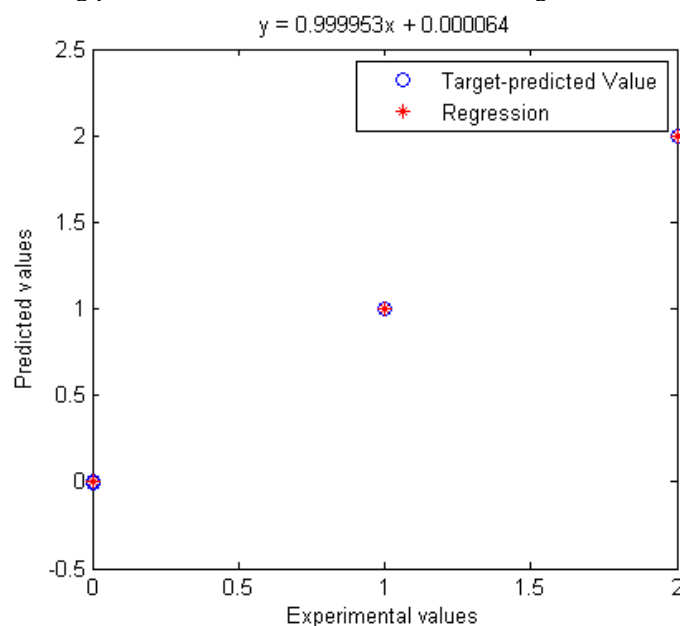


**Fig. 8:** Training error related to Db9



**Fig. 9:** Training error related to Db20

The obtained data set was included standard deviation in fourth level of packet wavelet transport used as input for the ANFIS model and the numbers {0, 1, 2} used as ANFIS model output while number 0 represented normal gear, number 1 represented wear gear and number 2 represented break gear. And between values is a represented severity of fault. Thus, ANFIS model has two inputs and one output. Some statistical methods, such as the Root mean squared error between the two-stage model and the validation data for all tests (RMSE), correlation coefficient (R), sum squared error (SSE), Mean absolute error, (MAE) mean square error (MSE) are used to showed the predicted model validation. For modeling of the classification function predicting the faults, the performed ANFIS model was trained for 100 epochs and gbell MF with 36 rules used for membership function of input. The predicting performance related to Db9 is shown in Figure 10.



**Fig. 10:** Predict and experimental value related to Db9

In addition, the realized simulations and their predicting performance by using different Db is tabulated in Table 3.

**Table 3:** Predicting performances of ANFIS model with different Db for the predicted fault

	RMSE	R	SSE	MAE	MSE
Db4	0.000207	0.999949	0.0000175	0.0000979	5.0083E-08
Db9	0.00068	0.9999997	0.000138	0.000208	3.9404E-07
Db20	0.00293	0.9999913	0.004055	0.000946	0.0000115

The best performance was obtained with Db9 mother wavelet. The RMSE value is 0.00068 and the R value is 0.9999997.

#### Conclusions:

In this paper, we have proposed a popular fault diagnosis method for mechanical equipment based wavelet packet transform. In order to possess time invariant property, the redundant second generation wavelet packet is presented. Because the length of the coefficients at each level is equal to the length of raw signal after decomposition, the wavelet packet coefficients can retain more faulty information, and hence can be extracted more distinguishing statistical features for classification. The paper has presented the use of the adaptive neuro-fuzzy inference system method based on the WPT for predicting different fault categories and severities. The vibration signal takes from experimental platform in tree condition of Gearbox's number one gear. Tree type of Daubechies (Db) mother wavelets such as Db4, Db9 and Db20 performed for preprocessing of vibration signal. The Feature vector was also obtained from standard deviation of wavelet packet coefficients acquired from tree type of Daubechies at fourth level of decomposition. Compared result show that Db9 has the best performance. The RMSE value is 0.00068 and the R value is 0.9999997 and the SSE is 0.000138 and MAE is 0.000208 and MSE is 3.9404E-07 for best performance.

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