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Fault Diagnosis of Gearbox using Machine Learning and Deep Learning Techniques

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Abstract*: Gearbox is an important component used for automobiles, machine tools, industries etc. Failure of any component in gearbox will cause huge maintenance cost and production loss. Failure should be detected as early as possible in order to avoid sudden breakdown which even cause catastrophic failures. Vibration signals are used for machine condition monitoring for predictive maintenance and efficiently predicts fault in the gearbox. In this paper signals from vibration is used for diagnosis of gearbox fault. The experiment uses four different conditions of gearbox in four different load conditions. Then statistical feature extraction is done and obtained result is given to Decision Tree, Support Vector Machine (SVM), Convolutional Neural Network (CNN) and Deep Neural Network (DNN) for fault diagnosis. The efficiency of these four techniques is compared and shows that machine learning is better than deep learning in gearbox fault diagnosis.

***Keywords* : CNN, DNN, Machine Condition Monitoring.**

I. INTRODUCTION

In industries gearbox is an important device to vary speed as well as load according to the requirements. Day by day it's industrial application increases and thus should give more importance to its design. The failure should be avoided in order to reduce the operational as well as maintenance cost [1]. Condition Monitoring reduces chances for catastrophic failures and thus reduces Maintenance cost. Various sensors like accelerometers placed on machineries are used to obtain vibration data. With the help of this data machine health is observed [2]. Analysis by using vibration signals are one of the most useful method in condition monitoring than other methods. Acquired vibration signals require feature extraction and classification methods in order to find condition of a machine [3]. Raw data is very huge when compared to feature extracted data. Feature extraction is very important in fault diagnosis. Different parameters are assigned for statistical feature extraction. Statistical analysis of collected data reduces the complexity of data and will reduce analysis time with almost same accuracy [4].

Machine condition monitoring depends on classification efficiency. To improve the accuracy of machine condition monitoring a technique with better classification efficiency should be find out. Machine learning techniques are compared with deep learning techniques in order find out better one. Decision Tree is a simplest method used to find classification efficiency and having a tree like structure [5]. In SVM a set of inputs with output values is given to learning machine and it builds line between two different sets of data which separates the sets of data. SVM correctly classifies the data and by comparing with wrongly classified data efficiency of SVM can be measured [6]. On huge number of datasets deep learning techniques having dropout systems are usually used in order to obtain a better result. A high epoch value is used for dropout technique in order to obtain high classification accuracy [7]. Classification efficiency becomes lower when applying DNN and CNN directly on feature extracted data. CNN and DNN models consist of three layers including input, output and multiple hidden layers. CNN is having multiple convolutional layers along with multiple pooling layers as hidden layer where DNN is having interconnected multiple hidden layers. In most of the cases CNN gives better result than DNN [8].

In the experiment, an accelerometer is placed above the gearbox to obtain vibration signal for four different conditions. Statistical feature extraction is done from the signal and this extracted data is given as input signal to SVM, Decision Tree, DNN and CNN for machine fault identification. These four techniques are compared and find out better one among these four techniques. Figure 1 shows methodology.

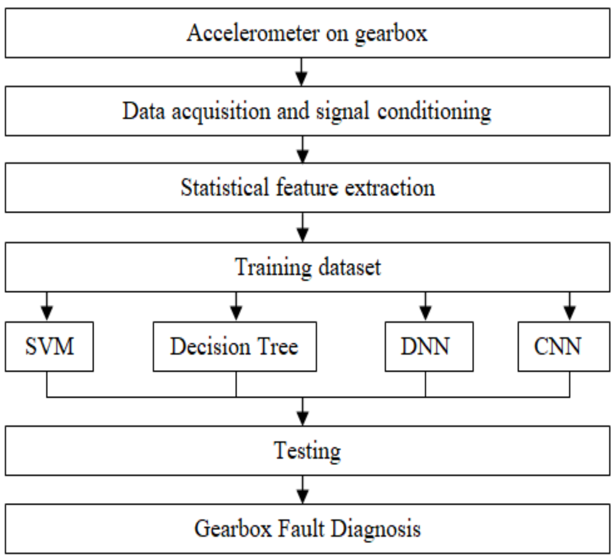

Fig.1. Methodology.

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II. EXPERIMENTAL SETUP

A. Submission of the paper

The experiment consists of three major equipments such as Gearbox, Motor and Dynamometer. Gearbox is driven by the motor and has control panel to vary speed of the motor from 50 rpm to 1440 rpm. Frequency, voltage and output current according to the different loads is recorded and stored in a data logger. Figure 2 shows the experimental setup.

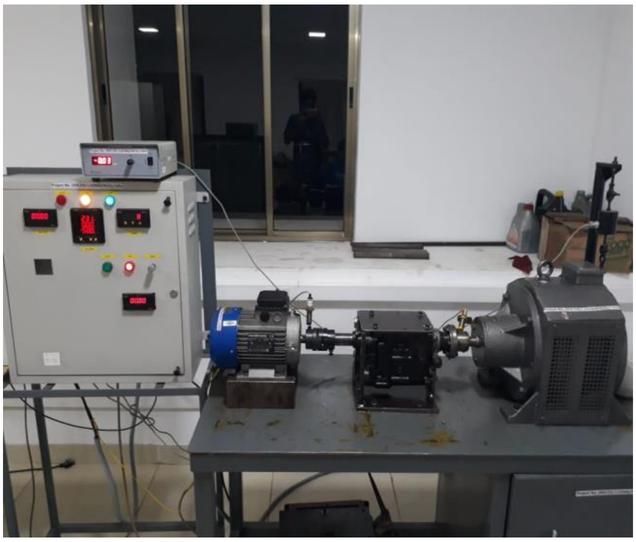

Fig. 2. Machine condition monitoring apparatus.

A four speed gearbox is used where second gear is engaged. Gearbox is coupled with a dynamometer. The load applied by dynamometer is varied from 0 Kg-m to 15 Kg-m using torque controller. The experimental conditions were shown in Table 1. Single motor input speeds, one gear speed, four loads and four conditions with total of 16 set of experiments are conducted is shown in Table I. Piezoelectric accelerometer is used as the sensor to collect vibration data. SO analyser is connected with output of accelerometer which analyses the collected data.

Table- I: Experimental condition

Type	Gear engaged	Speed (RPM)	Torque (N-m)
good gear	2^{nd}	500	0
			5
			10
			15
face wear gear	2^{nd}	500	0
			5
			10
			15
outer race fault bearing and	2^{nd}	500	0
			5
			10
			15
face wear gear along with outer race fault bearing	2^{nd}	500	0
			5
			10
			15

Gearbox is started by using the motor. At starting good gear and good bearing is fixed. Then the experiment was conducted by setting motor speed of 500 rpm and 2^{nd} gear is engaged by giving 0 N-m torque. After acquiring a consistent speed data acquisition will start till 300 seconds in the direction of Z axis and 8192 data samples were taken in one second and will continue the experiment till 235 seconds. The experiment is repeated for remaining 15 experiments by changing condition of gear, bearing and torque.

III. FEATURE EXTRACTION

Feature extraction method reduces original signal and a obtaining a new reduced signal. Collected data is too large which difficult to given as an input signal to the classifier which is reduced. Ten numbers statistical features are used in this work and they are mean, sum, median, minimum, maximum, mode, standard deviation, variance, kurtosis and skewness.

IV. FEATURE CLASSIFICATION

After extracting statistical features, the classification efficiency was calculated by SVM, Decision Tree, DNN and CNN. Four algorithms are compared in order to find the better classifier among them.

A. Machine Learning

Machine learning is an algorithm that accesses and learns from data. The objective of machine learning is computers are assigned learn from data. There are lots of different ways that machines can learn. The algorithms can be grouped into supervised, unsupervised, and reinforcement algorithms. The data that you feed to a machine learning algorithm can be input and output pairs in supervised learning algorithm or just inputs in unsupervised learning algorithm.

A.A. Decision Tree

A decision tree algorithm is working by control the program based on condition. It uses a tree like structure having main root node and multiple branches in order to give possible outcomes. The training data set S = s_1 ,s_2 ,... ,s_i are classified data samples. The data sample 's_i' is having 'i' number of dimensional vectors ($s_{1,i}$,$s_{2,i}$,... ,$s_{i,i}$) where '$s_{i,i}$' is sample feature and belongs to 's_i' class. In this work J48 algorithm is used as decision tree algorithm which creates a decision tree having multiple branches from the given training data and gives better classification accuracy. According to the training data set the algorithm recognizes attributes which correctly classifies the instances at high accuracy [9]. The overall classification accuracy is 89.75 %.

A.B. Support Vector Machine

SVM is a machine learning technique which uses 'N-1' dimension to obtain classification efficiency. SVM posses better classification efficiency. Collected data is given to SVM for obtaining classification efficiency. SVM classifies the data into two instances .One is classified correctly and another is incorrectly. SVM makes a separation line between these two instances. In figure 3 class 'A+' is denoted by symbol x and class 'A-' is denoted by symbol o. SVM places a boundary in between these two classes. [10]. The overall classification accuracy obtained is 92.06 %.

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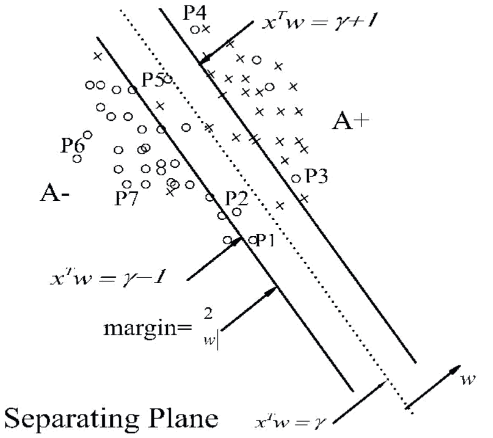

Fig. 3. SVM classification [M. Saimurugan et al., 6].

B. Deep Learning

Deep learning is an advanced version originated from artificial neural network which having input, output and multiple hidden layers such as pooling layer, convolution layers are present according to the type of algorithms[11]. Various deep learning techniques are used. Here DNN and CNN are reviewed.

B.A. Deep Neural Network

DNN is a neural network having input layer, multiple hidden layers and output layer. In DNN layers are ordered and each unit inside the layer is connected to unit inside the previous layer [12]. The illustration of DNN architecture is shown in the figure 4. The DNN used in this study is constituted three intermediate layers with input and output layer. The DNN finds the correct mathematical method to turn the input into the output, whether the relationship is linear or non-linear. The DNN moves through all the layers to calculate the probability of each output. DNN was simulated after training with given input data. In this work training data is having 70% of overall data and testing data is having 30% of overall data. Classification efficiency obtained by DNN is 67.08%.

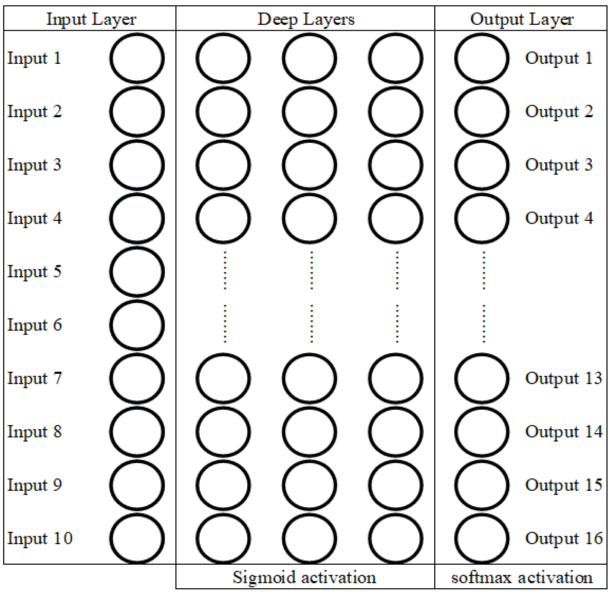

Fig. 4. DNN architecture.

B.B. Convolutional Neural Network

CNN is similar as that of DNN but having convolution layer as hidden layer. CNN is having multiple hidden layers in between the input and output layer uses a convolution filter for image processing as well as data processing. The hidden layers of CNN is having convolutional layers along with pooling layers. CNN was trained and tested with input data [13]. The CNN used in this study is constituted by an input layer, One convolutional layer using relu activation function, two pooling layer and an output layer. The illustration of DNN architecture is shown in the figure 5. In this work training data is having 70% of overall data and testing data is having 30% of overall data. Classification accuracy obtained by CNN is 72.02%.

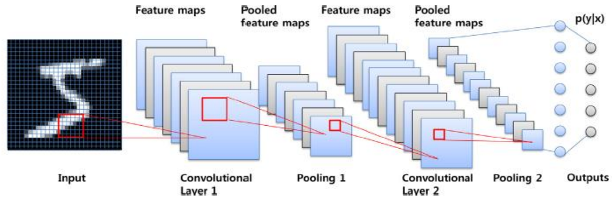

Fig. 5. CNN architecture[Y. J. Yoo, 13].

V. RESULT AND DISCUSSION

The classification efficiency in gearbox fault analysis obtained by SVM, Decision Tree, DNN and CNN are analysed and compared. The classification efficiency of four techniques is shown in the table II. SVM, Decision Tree, DNN and CNN are having classification efficiency of 92.06, 89.75, 67.08 and 72.02 percentages respectively. Among this four methods SVM posses higher classification efficiency and classification efficiency obtained by machine learning techniques is higher when compared with deep learning techniques. The result proves that machine learning technique is effective in gearbox fault diagnosis.

Table- II: Classification accuracy of machine learning and deep learning techniques

Algorithm	Machine learning		Deep Learning	
	SVM	DT	DNN	CNN
Classification accuracy	92.06%	89.75%	67.08%	72.02%

VI. CONCLUSION

Machine learning is an important technique used for automated fault diagnosis. The deep learning techniques are an emerging technique in AI based applications. Classification accuracy of four fault classes was obtained using SVM, Decision Tree , DNN and CNN. The accuracy of these four different techniques is compared. It has been observed that classification accuracy obtained by SVM is higher compared to other techniques. The machine learning techniques are more feasible in automated fault diagnosis of gearbox.

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