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Fault diagnosis in IC Engines Using Audio Signal

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Abstract

The use audio signal for fault diagnosis in four strokes Internal Combustion Engine has grown significantly due to advances in the progress of digital signal processing algorithms and implementation techniques. A fault diagnosis in internal combustion engine using digital signal processing technique with MATLAB and Artificial Neural Network is proposed. The present paper discusses a methodology where a set of parameters is used to checks the status of an engine as either faulty or non-faulty. This method based on parameter estimation, modal approaches are developed to generate several symptoms indicating difference between faulty and non-faulty status.

Index Terms: *Internal Combustion Engine, Digital Signal Processing, Artificial Neural Network, Parameter Estimation*

Abbreviations*- IC-Internal Combustion, MLP- Multilayer perceptron, SOFM- Self-organizing feature maps (SOFMs), PCA- Principal Component analysis, JEN- Jordan and Elman networks, SVM- The Support Vector Machine, ACA – Average Classification Accuracy.*

1. INTRODUCTION

The classical approaches are limited or trend checking for supervision, fault detection and fault diagnosis. As they do not give a deeper insight and usually do not allow a fault diagnosis so, a model-based method of fault detection has to be developed [2]. Determination of fault at an early stage and repairing them before it leads to larger fault is important, because it reduces the other damages, repairing cost and also reduces down time of the engine [3]. This paper discusses the faults due to spark plug, the details of spark plug fault as under.

1.1 Spark plug

A spark plug is an electrical device that fits into the cylinder head of some internal combustion engines and ignites compressed petrol by means of an electric spark. Spark plugs have center electrode which is connected by a heavily insulated wire to an ignition coil circuit on the outside. As the electrons flow from the coil, a voltage difference is developed between the center electrode and side electrode. Fuel and air in the gap act as an insulator restricting the flow of current, but with further rise in the voltage, the structure of the gases begins to change between the electrodes. As the voltage exceeds the range of dielectric strength of the gases, the gases becomes ionized and it becomes a conductor and electrons starts flowing across the electrode gap. For proper firing of spark plug voltage in excess of 20,000 volts is required. Because the spark plug is inside the engine and is the only easily removable part it can be used as an indicator to the Faults in Spark Plug.

Normal Spark Plug*:* Combustion deposits are slight and not heavy enough to cause any negative effect on engine performance. Brown to grayish tan color and minimal amount of electrode erosion which clearly indicates the plug is in the correct heat range and has been operating in a "healthy" engine.

Inappropriate Plug Gap: In appropriate plug gap is developed because of routine damage like mechanical damage caused by a foreign object that has accidentally entered the combustion chamber. This condition may also be due to inappropriate reach spark plugs that permit the piston to contact or collide with the firing end.

The gap may also because the plug has served its useful life and should be replaced. It can be used for additional miles of travel with approximately doubled voltage required for firing the plug. Higher voltage requirements are needed above normal, in quickly accelerated engines. loss in fuel economy and Poor engine performance are signs. of a worn or spoiled spark plug. Accumulated rough material on the side electrode may melt to bridge the gap when the engine is suddenly put under a heavy load may cause the inappropriate spark plug. The normal and faulty spark plug with inappropriate gap is shown in Fig.1.

Fig1 a. Normal Gap

Fig1 b. Inappropriate Gap

With the rapid development of the signal processing techniques, the sound emission and vibration signals can be used in condition monitoring and fault diagnosis because they always carry the dynamic information of the mechanical system [2, 5].

2. System Overview

It will be acceptable for vehicular system that it must have vehicle information system. To develop such system, detail analysis of the fault is required. The working of the system is shown in the block diagram Fig 2. The parameters of recorded sound signals are extracted using the Simulink in MATLAB software. The detailed analysis is carried out using neural networks and finally the optimal neural network is designed.

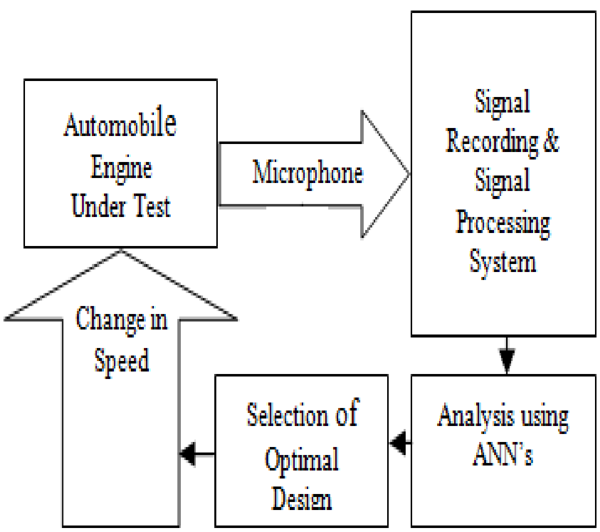

Fig. 2: Block Diagram of the System

Fig. 3: Experimental Setup with audio signal capturing system

3. Experimentation and data collection

Figure 3.Shows the Experimental Setup with four stroke IC engine, Audio signal capturing and recording system. The sensor used to record the audio signal is Carbon microphone which is placed near the engine head so that, it will capture the audio signals from the engine. Audio signal carry valuable information about the engine behavior and status of engine. The engine used is a four stroke, single cylinder IC engine of Honda Shine the detail specification is as in table 1:

The sensor used is a simple carbon microphone which is directly connected to the 3.5mm connector of Laptop or PC. The **sensor used has** specifications as in table 2.

Initially engine was started in healthy condition and signals were recorded at different speed i.e. 1000 rpm to 3000 rpm with 500 rpm interval. Then the normal spark plug is replaced by faulty spark plug and signals are recorded again at same speed. The simulink model was used to record the sound signals captured by carbon microphone from the engine is shown in fig. 4 These audio signals are processed using Simulink in MATLAB to find the parameters as minimum value, maximum value, mean value, energy, standard deviation and variance. The Simulink model for parameter extraction is shown in Fig. 5

Table 1: Specification of Honda Shine Engine	
Model Designation	Air Cooled, 4 Stroke OHC Single Cylinder
Starting	Self Start/Kick Start
Displacement	998cc,DOHC,16 valves
Transmission	Constant Mesh, 4 speed gears
Displacement (cc)	124.6
Gear Shift Pattern	All Up
Carburetor	CV Type
Acceleration	0-60 kmph in 5.3(Sec)
No. of cylinders / layout	Single Cylinder
Cooling Type	Air Cooling

Table 2: Specification of Sensor	
Frequency ranger:	50-16KHZ ,
Impedance	low
Sensitivity	-60dB+/-3dB
Cable length	180cm
3.5mm Plug Microphone Size	26X15X12mm
Weight	30g

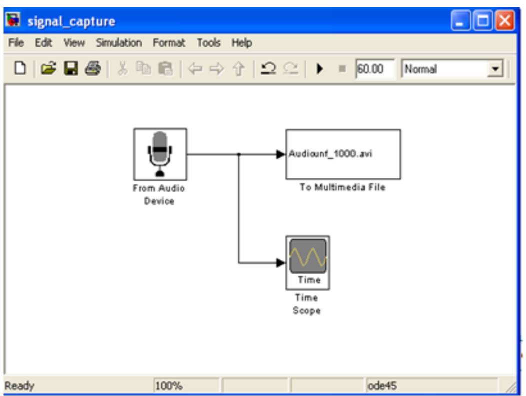

Fig.4: Simulink Model for Signal Recording

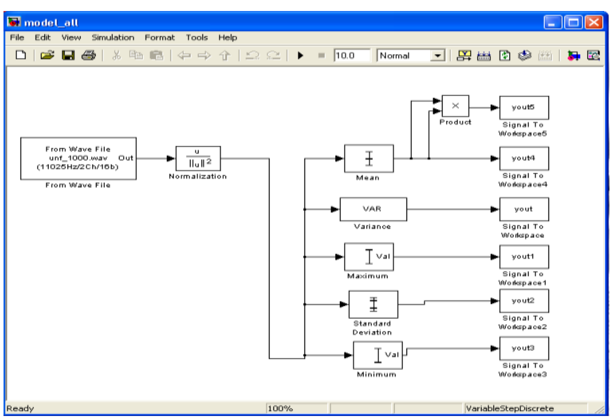

Fig. 5: Model for parameter calculation

4. DATA PARTITION FOR ARTIFICIAL NEURAL NETWORK

Signals are overlapped and are highly complex for faulty and non-faulty therefore ANN has been employed for analysis of the fault. In proposed system the performance of MLP, MNP, SOFM, PCA, JEN, RBN, SVM are tested for fault detection in an automobile engine. The audio signal of length 50 second with 551250 samples is used. Considering six parameters mean of signal, maximum value, minimum value, standard deviation, variance and energy of the audio signal, the input matrix for ANN becomes (6 X 551250) out of which 65% samples are used for testing, 25% for cross validation and 15% are used for testing of neural network. The Kernel Adatron is specially used for Support Vector classifier which classifies the fault. A classification task usually involves separating data into training and testing sets.

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Table 3: Performance of ANN for Spark Plug Fault

ANN	HL	PE	ACA
MLP	One	52	96.12
MNN	One	53	93.89
SOFM	One	50	94.68
PCA	One	50	92.19
JEN	One	50	91.29
RBF	One	50	87.80
SVM	Epochs- 650		97.75

Table-3: Performance of ANN for Spark Plug Fault

Fig.6: Linear Support Vector Machine Classifier

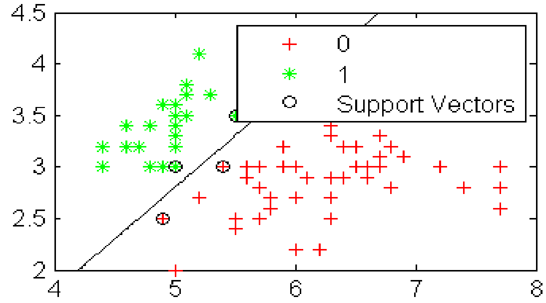
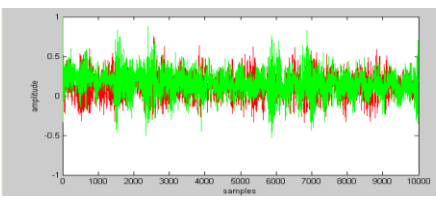


Fig.6: Linear Support Vector Machine Classifier

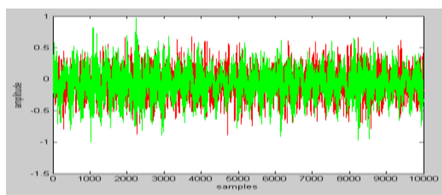
5. RESULTS AND OBSERVATIONS

The recorded audio signals are normalized and plotted as shown in fig.7. Faulty (Red) and Non Faulty (Green) Audio Signals



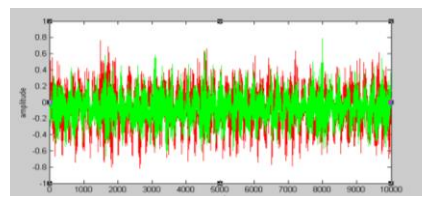
Red- faulty
Green- Non faulty

Fig.7 a. Signal Plots At 1000 rpm



Red- faulty
Green- Non faulty

Fig.7 b. Signal Plots At 2000 rpm



Red- faulty
Green- Non faulty

Fig.7 c. Signal Plots At 3000rpm

Fig. 7: Signal Plots for Normal and Faulty condition

It is observed from the plots that

i. The amplitudes of the signal for Faulty Spark Plug are smaller than that for Non Faulty Signals.
ii. There is no separation between faulty and normal signals.
iii. The mean value of faulty signal is shifted down as compared to the mean value of non faulty signal.

In Artificial Neural Network, the neural network is first trained by using the parameters extracted from audio signals with number of Epochs equal to100, number of Hidden layers equal to 2, and 'Logsig' Transfer function. The Performance and Regression plots are shown in figure fig.8

It is observed from the regression plot that, the model developed fit s to the data. The regression for Training, Validation & Testing is 0.99823, 0.98817 and 0.97862 the overall regression is found to be 0.99231. After training using benchmark data, unknown signal is applied to it and thus the fault is detected by Neural Network comparing the parameters of unknown signal. The signal for spark plug fault is applied as unknown signal to the trained neural network, the output window showing the result of system is shown in fig.9 which shows 'Engine has Spark Plug fault'.

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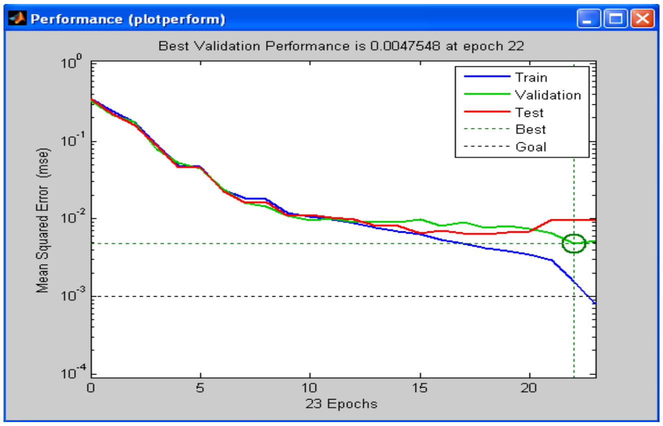

Fig.8 (a): Performance Plot

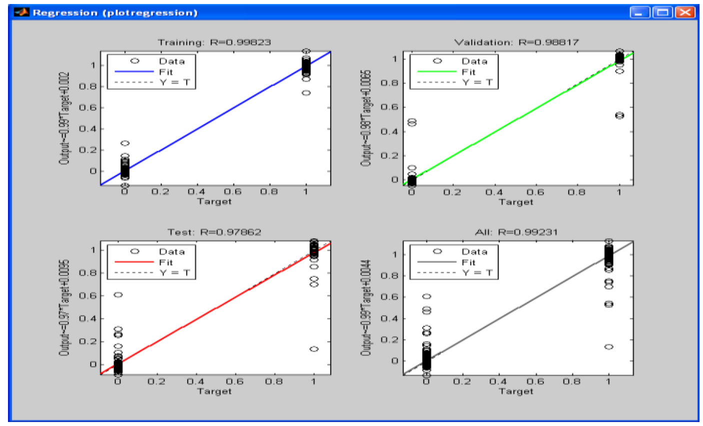

Fig.8 (b): Regression plot for Training, Validation & Test

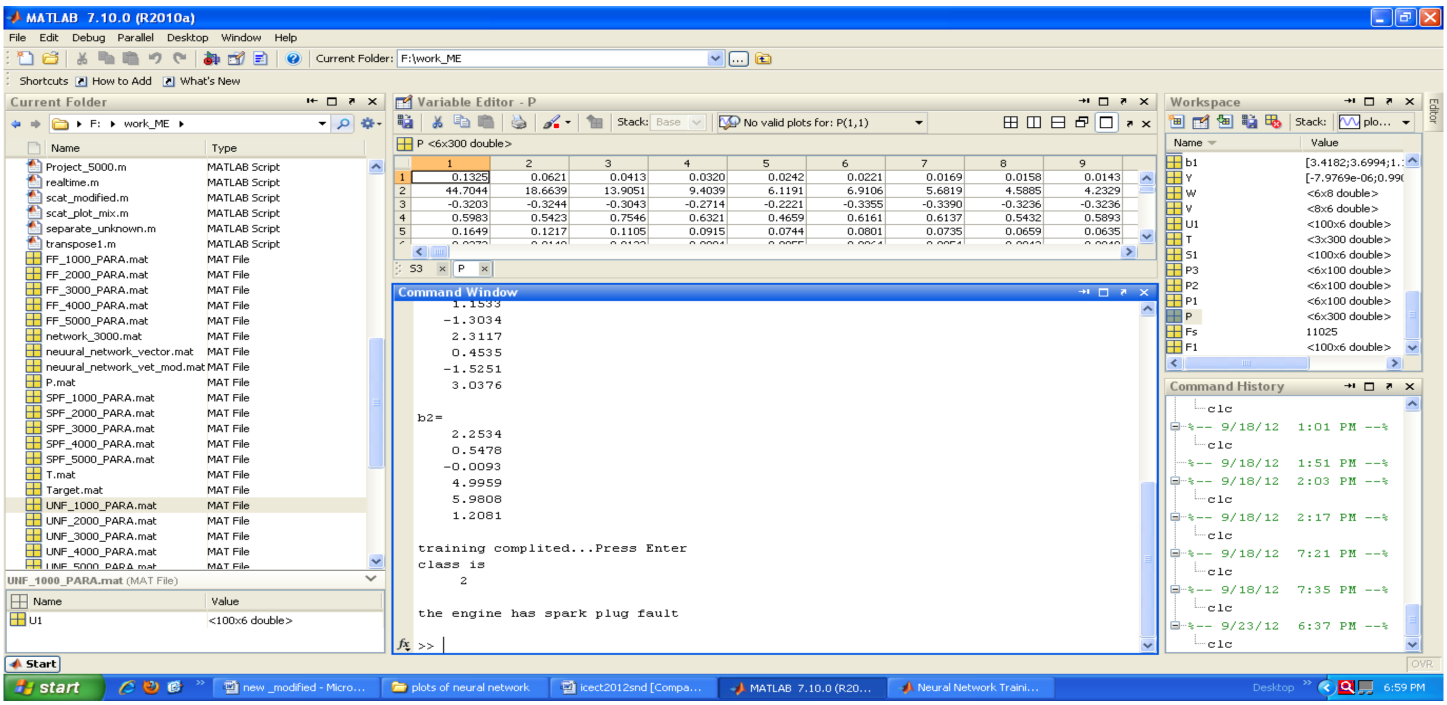

Fig.9: Output window of the system

Conclusion

From comparative study of all types of neural networks for Spark Plug Fault is shown in the table 3. It is depicts that, the SOFM, MLP and SVM are giving performance better than seven neural networks , it is also observed that performance of SVMNN is found to be the best amongst all seven ANN and therefore it is proposed that SVM can be preeminent classifier to detect spark plug fault in a four strokes IC engine**.**

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