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Research Paper

VALIDATION AND PREDICTION OF THE DIESEL KNOCKING INDEX BY USING ARTIFICIAL NEURAL NETWORKS

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Impulsive Diesel Knocking is one the major issues of vehicle acoustics in Diesel Engines. It is thus necessary to provide a metric to measure the intensity of noise of the vehicle. This paper presents a method to validate and predict the intensity of Diesel Sound. Impulsive Diesel Knocking Index provides a metric to quantify the Diesel Knocking perception of the customer. The methodology includes subjective evaluation and objective evaluation of the Diesel Knock. The subjective evaluation of the Diesel Knocking is done by a team of experts in psycho acoustics who rate the quality of diesel engine sound. The objective evaluation of the diesel sound is done by LMS Test Lab software. LMS test Lab provides loudness, sharpness and roughness values of the sound. Artificial Neural Networks, computational models which used to estimate or approximate function, is used to validate the Diesel Knocking Index based on the objective and subjective ratings. The impulsive Diesel Knocking index is predicted using Artificial Neural Network.

Keywords: Diesel knocking index, Artificial neural networks, Sound quality evaluation

INTRODUCTION

In this modern age, the human race is facing a major issue of noise pollution. From the studies made in last few decades, it is observed that 40 percent of environmental noise is being contributed by vehicles (Ralph Heindricks and Markus Borden, 2005). Also, a study suggests an increase in vehicle interior noise increases the probability of accidents due to psychological effects on the driver. There arises a need to quantify the noise and propose methods to decrease the noise of the vehicle. Vehicle noise is of various types namely gear whines, wind noise, rattle, knocking. This paper proposes a method to quantify and predict diesel knocking, one of the major sources of vehicle noise.

Diesel knock is the metallic, impulsive noise which is unpleasant and disturbing in nature. Product sound and sound quality are key aspects of product perception (David Lowe *et al.*, 2011).

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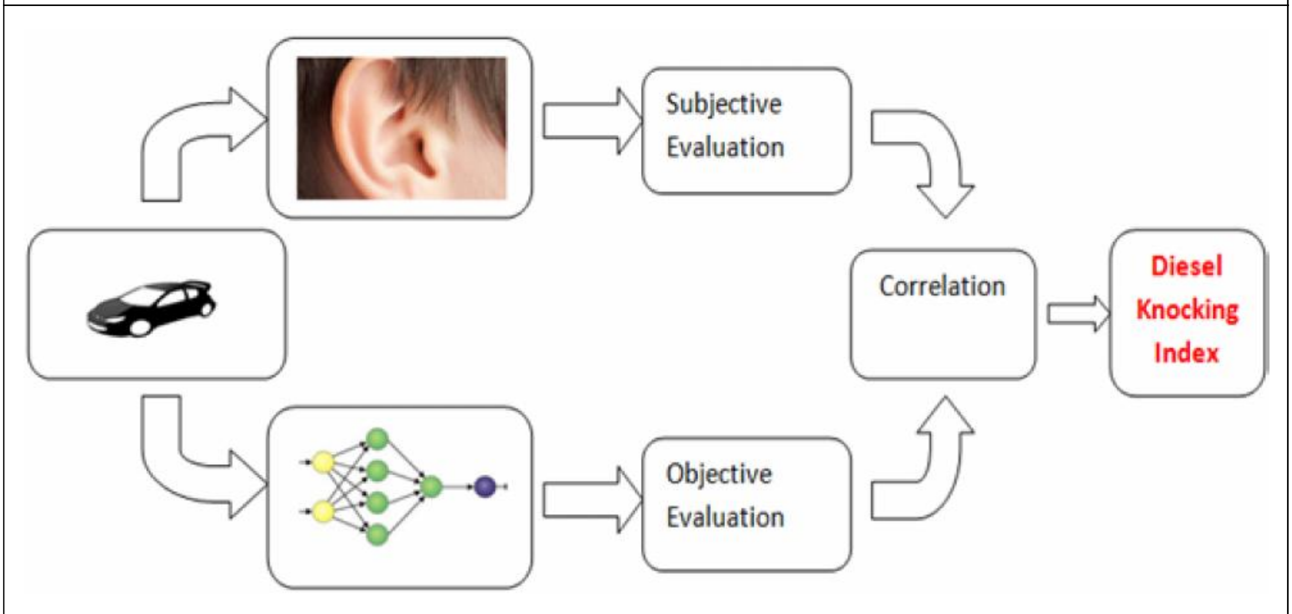
How a product sounds plays a critical role in conveying the right message about its functionality, comfort, overall brand image and quality. The consumers these days prefer more of a pleasant sound like a gasoline engine. Therefore, it is necessary to estimate the diesel sound so that the customer's perception is achieved before the vehicle is launched in the market. Thus saving the time and resources required for obtaining customer reviews about engine sound quality and taking necessary measures in the design phase of the vehicle.

In sound quality engineering, the psychoacoustic indices such as the loudness, sharpness, roughness, fluctuation strength, etc., have been introduced to evaluate sound quality (Fastl *et al.*). These sound metrics are evaluated by using LMS Test.Lab software. The diesel sound is then evaluated on a subjective basis by rating it in terms of knocking sound. This paper proposes the use of artificial neural networks for obtaining a correlation between subjective and objective ratings of sound. The provision of artificial neural network assures accurate estimation of customer's perception.

DIESEL KNOCKING INDEX

In spark-ignition engines; knock, pinging or detonation are all the terms that have been widely used to describe the characteristic "metallic rattling" noise associated with abnormal combustion (Ralph Heindricks and Markus Borden, 2007). In the case of Diesel engines, knocking occurs when injected fuel auto-ignites and combusts in the premixed stage of combustion. Diesel knock is impulsive metallic noise occurring due to premature combustion of fuel in diesel engines (David Lowe *et al.*, 2011). Diesel Knocking does not have much adverse effect as knocking in spark ignition engines. However, diesel knock an important parameter considering engine performance and noise. Diesel knocking is mainly caused due to the use of contaminated fuels, faulty injection system, and unsuitable fuel substitution (David Lowe *et al.*, 2011). Thus, we can say that diesel

Figure 1: Methodology



knocking is directly associated with high combustion excitation. The knocking sound is dominant when the engine is run in idle condition.

Diesel knocking index is a metric developed in order to quantify the quality of sound in terms of impulsiveness or knocking. The customer's perception of the sound quality is an important factor for the vehicle. Diesel Knocking index provides a metric for diesel sound quality.

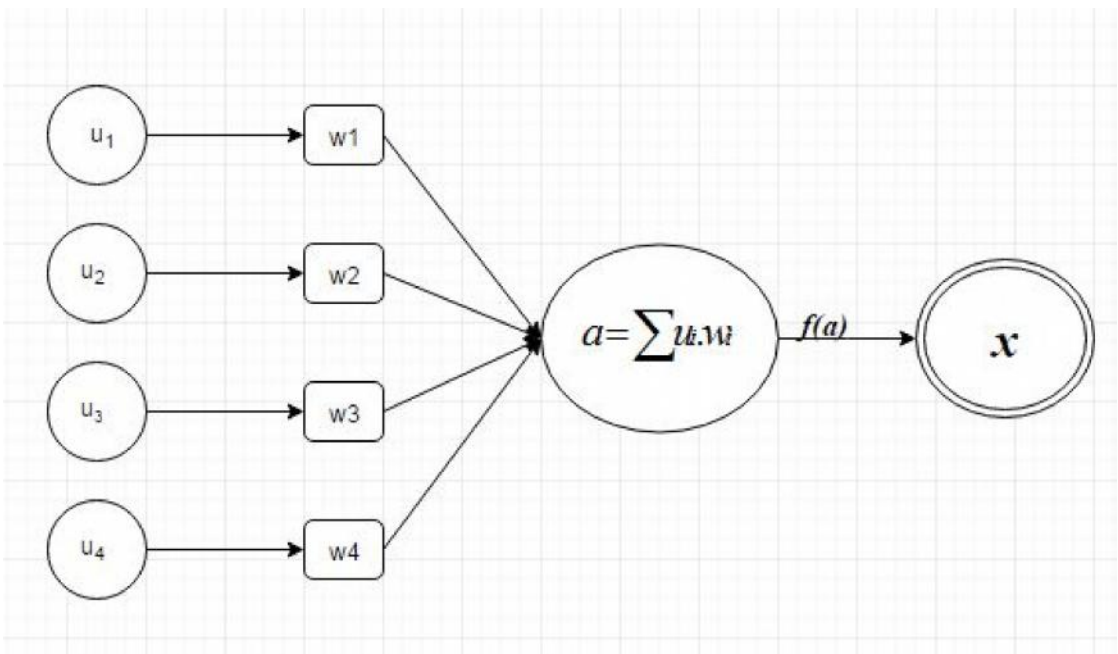
ARTIFICIAL NEURAL NETWORKS

Artificial Neural Networks are computational models inspired from biological neurons from brains of a living being. Neural Networks are used to estimate or approximate functions that depend on a large number of inputs which are generally unknown (Robert Uhrig, 1995). These are a system of interconnected neurons which compute values from input and estimate output (Vidushi Sharma *et al.*, 2012).

The figure shows a typical model of ANN neuron. Inputs are depicted as $u_{s,}$ weights as $w_i$andoutput of neuron as *x*. Whereas *f(a)* is the application of activation function which can be linear, threshold or sigmoid. The inputs are multiplied by their corresponding weights and are summed up to obtain function 'a'. This function '*a*' is then multiplied by a transfer function to obtain the output '*x*'. A neural network may consist of various layers namely input layer, an output layer, and hidden layers.

The Back Propagation (BP) algorithm is the most commonly used training method for feed-forward networks. In order to train a neural network to perform some task, we must adjust the weights of each unit in such a way that the error between the desired output and the actual output is reduced. This process requires that the neural network compute the error derivative of the weights. In other words, it must calculate how the error changes as each weight are increased

Figure 2: Model of a Neuron



or decreased slightly. The back propagation algorithm is the most widely used method for determining the change in error (Vidushi Sharma *et al.*, 2012).

VEHICLE NOISE MEASUREMENT

In this paper, vehicle noise is analyzed with LMS Test.lab which provides us with sound metrics like loudness, sharpness, and roughness. LMS Test.Lab integrates acoustic testing capabilities and provides scalable solutions for on the spot sound testing and analysis. The testing was carried out in a quiet room, which is completely isolated from the external noise. The room is such that there are no echoes and refractions ensuring distraction free and accurate measurement of the engine noise. Five microphones and a triaxial accelerometer are used for recording the sound and vibrations. The sound measurement is done in hot knocking condition that is at normal temperature. It is observed that knocking occurs predominantly in idle engine condition. So, the sound is measured in idle engine condition.

The vehicle is parked on the test site as per the standard alignment. The setup of auxiliaries like Microphones and Accelerometer is done as per the standards of noise measurements. Figure below shows the test setup.

Locations of microphones are adjusted such that it replicates the location of the human ear. The engine noise is measured for about 12 to 20 seconds. The measured sound is further analyzed in LMS Test Lab and wave file of each vehicle is generated. Total 35 signals are measured which are prepared for further objective and subjective evaluations.

JURY TEST

The Jury Test was conducted for the subjective evaluation of the sound quality of vehicles tested. The jury was formed by a team of 10 experts having knowledge in the acoustic field. The test was being conducted in a sound quality room which isolates the external noise and gives clear and crisp engine sound for evaluation. All the necessary measures were taken to keep the jury unbiased considering their physical and mental condition.

To evaluate the quality of sound a measure between scales 1 to 10 was presented before the jury. The quality of sound here indicates the impulsiveness or knocking of diesel sound. The scale 1 representing sound with higher knocking and 10 representing least knocking. The audio files of all the vehicles having duration of approximately 18 seconds long were played sequentially. Four rounds were conducted for the evaluation of sound. Out of which first three rounds the audio files were played sequentially and for the fourth round the audio files were played randomly. After hearing each audio file of the vehicle the sound is rated on the scale of 1 to 10 considering knocking as the main source of noise. Further, the rating of each vehicle is averaged and is taken as an impulsive knocking index for the vehicle. The table below shows Knocking Evaluation Sheet representing the knocking acceptance scale.

Table 1: Diesel Knocking Index Evaluation Sheet

	Not Acceptable	**Acceptable**
Evaluation	1 to 4	5 to 10
Meaning	Worst knocking	Medium Knocking to No knocking
Rating		

MODELLING OF NETWORK

The decision of number of layers is made depending upon the type and number of inputs and outputs. In this work we have three inputs and one output. A three layered feed forward network is selected. The input neurons to the network are the sound metrics namely loudness, sharpness and roughness. The input matrix 'I' can be written as

$$I = [\text{Loudness Sharpness Roughness}]^T$$

In this paper we have taken 35 vehicle noise samples. Therefore the input matrix comes out to be 3 × 35. Similarly the output layer consists of one neuron that is of diesel knocking index. The dimension of the output matrix 'O' will be 1 × 35.

The number of hidden layer for the network is selected to be as 1. The number of neurons for the hidden layer is calculated by the empirical formula as given.

Figure 3: Neural Network Architecture

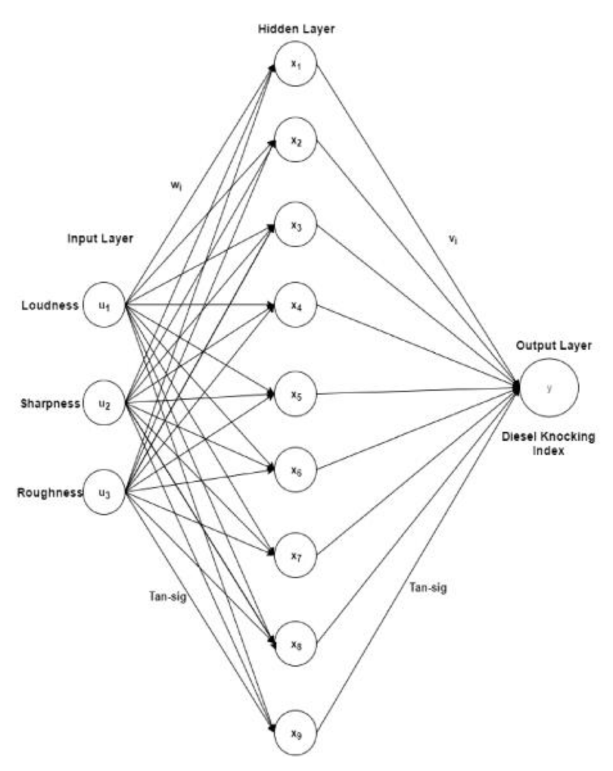


Figure 4: Correlation of 0.9832 at Epoch 659

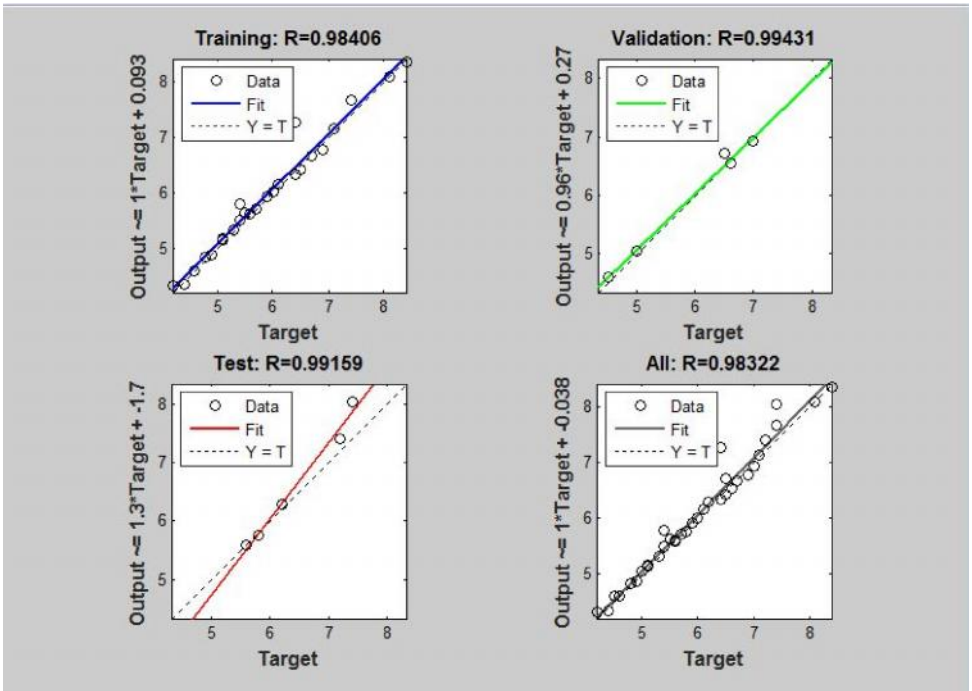
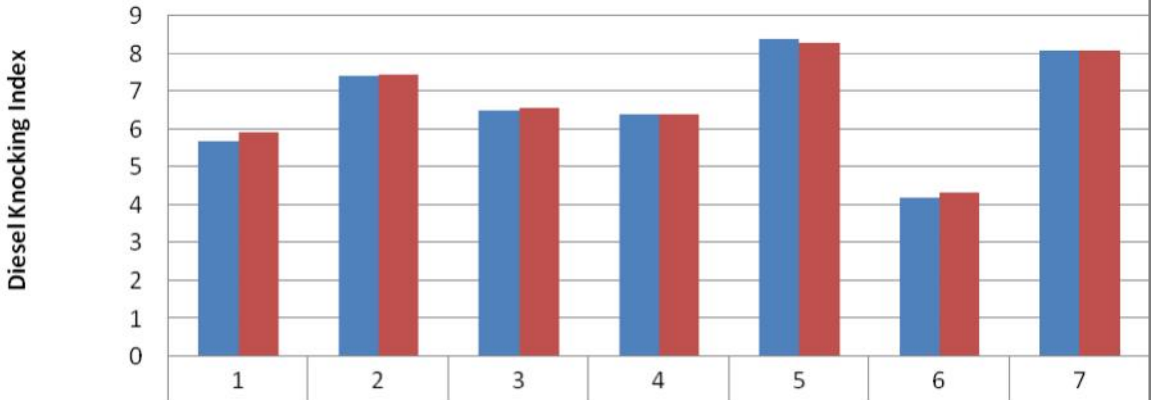


Figure 5: Prediction of Neural Network



	1	2	3	4	5	6	7
Actual Rating	5.7	7.4	6.5	6.4	8.4	4.2	8.1
Predicted Rating	5.9295	7.4294	6.5586	6.388	8.2881	4.3261	8.1033

$H = \sqrt{I} + C$

'H' is number of neurons for the hidden layer. 'C' is constant which can be from 1 to 10.

To find optimum number of neurons in hidden layer, error is calculated at each value of 'H'. The optimum number of neuron was found to be 10 having the least error. Figure shows the network diagram.

RESULTS AND DISCUSSION

The numbers of samples are divided by the tool in 3 sets namely training, validation and testing. The proportion can be manually fed to the tool but we choose standard division. Training phase consists of 70% of sample data, validation consists of 15% and testing consists 15% of data. After validation of the network correlation of 0.9832 is obtained which denotes only variation of 0.0168.

After validating the network, sample input was provided to the network to predict the output that is Diesel Knocking Index. For the same input values actual rating was obtained from the jury test. The graph below shows the variation of rating for 7 samples which was predicted.

CONCLUSION

The sound of vehicle affects the comfort and safety of vehicle. Diesel engine vehicle have issues related to sound quality compared to gasoline engine vehicles. Diesel knocking index is one of the major contributors of vehicle noise. In this work, we have presented a metric to quantify the quality of sound on the basis of impulsive diesel knocking index. Subjective and objective evaluation of the measured sound of vehicles is done.

Artificial Neural Network is used to correlate the objective and subjective ratings of the noise. The network is trained by Back propagation algorithm. Correlation of 0.9833 is obtained by training the neural network. The same network is used for prediction of Diesel Knocking Index. From the samples predicted maximum variation of 4 percent was found out.

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