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`Prediction of the overall sound level of diesel engine with bioethanol & diesel blend fuelsby help of back-propagation error algorithm

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Abstract

MF399 tractor, is one of the common tractors used in agriculture in Iran. Due to the reduction of fossil fuels and environmental considerations, these days, tendency to use renewable fuels such as biodiesel, bioethanol and biomethanol in compound with diesel fuel has increased. Given the importance of noise and its effect on the driver's mental,other pass-by peopleand physical health at work, the sound volume resulting from the use of bioethanol fuel in a tractor engine was examined and compared with the noise of diesel fuel. In this study, artificial neural networks are used to predict the noise level of MF399 tractor. Test site was prepared exactly according to international standards and signals emitted from the vehicle were measured, then the overall sound level values were obtained in the frequency domain. The results showed that the multi-layer perceptron network with back propagation error algorithm, two hidden layer, three neurons in the first hidden layer and two neurons in the second hidden layer to predictthe overall system noise of vehicle at other pass-by people position is Influenced by engine speed input variables and different blend fuels is suitable.

Keywords: “Noise, Diesel Engines, Artificial Neural Networks, Multi-Layer Perceptron, Back Propagation (Error) Algorithm”.

1.Introduction

Compression ignition engines (diesel) have been used extensively in human life. Utilization of engines in agriculture, transport, industry, submarines, thermal power plants and cars has been common in recent years. Although diesel engines in terms of thermal efficiency and savings in fuel consumption and therefore consumer spending and longevity, are better than gasoline engines, but in terms of noise pollution are in trouble. Noise or unwanted sound are considered one of the most important harmful physical factors. they cause a lot of problems for the driver and the environment. If the sound intensity level exceeds the allowable threshold not only leads to hearing loss, high blood pressure, headache, fatigue, irritable and angry driver, but also increases human error and decreases productivity at work (Roth*et al*1991؛Hassan-Beygi*et al* 2005؛ Crocker *et al 1998*). By definition, any unwanted sound in a listener's ear is called noise. Given the purpose of this paper, loud levels sounds that hurt human auditory system, are defined as noise. Whether it is pleasant or unpleasant sound (Anonymous,1996).

Given the hazards of noise on human health, safety and health, professional associations and organizations in different countries have imposed laws to limit the hours of work in such areas from which we can mention NIOSH[2] laws (Anonymous,1996). According to the definition, exposure to the noise level higher than 85 dB (A) for 8 hours per day or 88 dB (A) for 4 hours is called a noise dose (Irwin *et al.*, 1979؛Crocker *et al., 1998*). Breste et.al as well as Dennis&may studies, show that the overall noise level at driver's ear position of tractor drivers without cabins or cabins with open windows, is in some cases higher than 95 dB (A) (Dennis *et al.*, 1995؛ Broste *et al.*1989). Noise level of most modern tractors, have been reported higher than 90 dB (A) however, the level of noise and other farm machines such as auto-combines, corn harvest machines, hammer mill and dryers have been reported higher than 100 dB (A) (Bean *et al.*,1995). Results by Italian researchers indicates that virtually all people who were about 20 years old tractor drivers, experienced some hearing loss, and 34% of them suffer major hearing loss (Crocker *et al., 1993*). Research by Solecki has described hearing loss in about 56% of the tractor drivers under study, about 20 dB (A) less than the same age control group and this is mostly related to drivers over the age of 30 years (Solecki,1965؛ Solecki,1965). The research was done by Hasan Beigi et al Bidgoli, used the artificial neural network to predict the noise of 13 hp power tiller. Test site was prepared according to international standards and sound signals released from the vehicle were measured, then the overall noise level values were obtained in the frequency domain. The results showed that the multi-layer perceptron network with back propagation error algorithm, two hidden layer, three neurons in the first hidden layer and two neurons in the second hidden layer to predict the overall system noise of vehicle at driver's ear position is influenced by engine speed input variables, gear ratio and the appropriate surface type (Hassan-Beygi*et al* 2005). According to the research on eight-cylinder diesel engine on a military vehicle, Guangzhou Poe et.al concluded that with increasing from 1800 rpm to 1900 rpm, the engine noise rises sharply. But with increasing engine speed from 1900 to 2200 rpm, engine noise level does not increase much. When the engine speed reaches 1900 and 2200 rpm intake and exhaust system noise effects would increase. Noise level near the air inlet and exhaust pipe is about 120 dB (Guangpul *et al.,* 2006).

According to the above discussions, and with regard to starting the research and gaining technical knowledge of producing biofuels in Iran, and also to replace these fuels with fossil fuels and the need to analyze noise caused by the fuel blends on engine, the purpose of this study is to analyze the noise level of MF399 tractor at other pass-by people position with artificial neural networks. The use of artificial neural networks can be seen as an appropriate way to estimate thelevel of noise with desired accuracy. The result of such a study would be useful in the selection of appropriate values of the studied parameters, to produce less noise than 85dB(A) standard, and also in the formulation and implementation of strategies used to protect the driver and passengers.

2.Materials and Methods

2.1Testing tractor

In this project the impact of the integration of diesel fuel and bioethanol on engine noise were examined. The data from four-stroke, 6-cylinder engine noise of MF399 tractor that is made in Tabriz Tractor Manufacturing Plant, measured, recorded and were analyzed. Engine specifications are presented in Table 1.

Table1-Technical specifications ofMF399tractorengine.

Model	Perkins A63544
Manufacturer	Iran Tractor ManufacturingCompany
Number of cylinders	6
Cylinderstroke	127mm
diameter ofthe cylinder	98.6mm
Volume ofcylinder	5.8Lit
combustion	1,5.3,6,2,4
maximumpower at 2300 rpm	(82kw)110 hp

1-National Institute For Occupational Safety and Health

376 N.m	Maximumtorqueat 1300 rpm

2.2Tools and measurement equipment

A microphone was used to measure the noise. To the other pass-by people position, the microphone situated 1.2 metres above ground level at a distance of 7.5 metres from the path of the tractor's centre line. Microphone was placed horizontally balanced. To obtain noise signals of different treatments, an audio device of HT157 model was used (fig.1). The device is designed for measuring the sound pressure level (SPL) from 25 dB to 140 dB with a frequency in the range of 10 Hz to 20 kHz. Recorded sound waves are available both in analyzed and raw form. AC output voltage device is analog which is compatible with input signal (in dB). The device is portable and has a microphone and calibrator device. Noise omission for measuring device is done using the same calibrator. Noise signal at 5 engine speeds obtained in MF399 tractor (1700,1800, 1900, 2000 and 2100 rpm) for different fuel mixtures. Dynamometer was used to change the applied charge and spin on the engine. Dynamometer (NJ-FROMENT Σ5) was used by the british company(fig.2). The dynamometer through a magnetic field is applied, the amount of power and torque to automatically measure.All experiments were performed in all cases with four repetition.

2.3 Characteristics of the test site

Test site was selected accurately based on the standards of international standard Organization (Anonymous,1996)andAutomotive Industry Standard(Anonymous,2009). The site was in a location of open space, free of trees, dirt, and buildings. To minimize the effect of environmental factors, wind speed in the site was of 5m/s at the maximum, measurements were not performed during rain and lightning, and also the ambient noise level in the test was 10dB less than the minimum sound level measured (Anonymous,2009). The dimensions of the area is shown in Figure 3.

Figure(1) Soundmeasuring devicesused inthisresearch.

Figure(2) Dynamometerused inthisstudy.

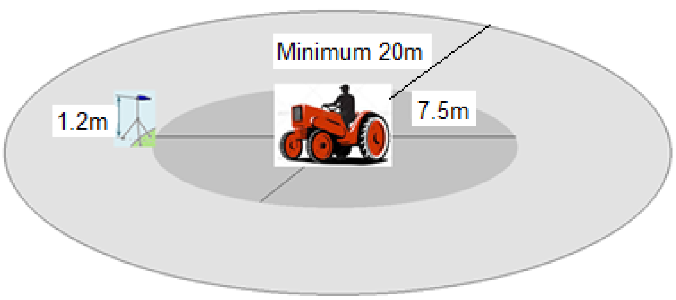
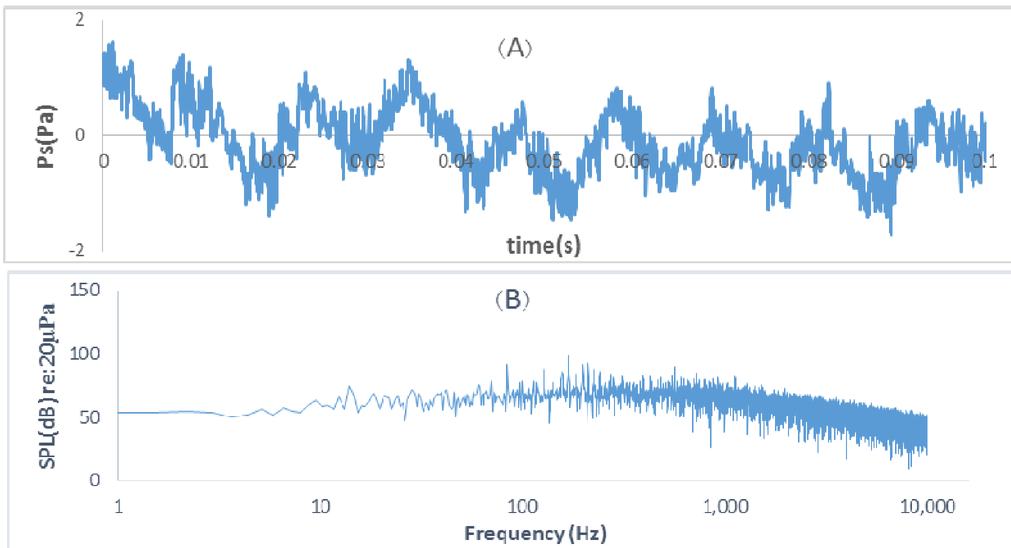


Figure (3) Size of the intended area for testing.

2.4 Data capture and data processing method

Experiments were performed in stationary mode on a selected MF399 tractor engine. The independent variables in this study consisted of a mixture of seven different fuels (E0, E2, E4, E6, E8, E10 and E12) and 5 levels of engine speed (1700,1800,1900, 2000 and 2100 rpm). After setting the desired values of the independent parameters (inputs), such as engine speed and the amount of combination of diesel fuel and bioethanol were tested on the engine of MF399tractor. The sound of the engine has been stored with the microphone for 20 seconds.Then the raw and analyzed audio signals were given and recorded in a computer via a USB. The engine used in this study was a 6-cylinder, four-stroke engine. The rate of sampling data according to the Nyquist measurement, was required to beat least two times the maximum frequency, to allow the conversion of analog output signals of sound meter device to be correct (Dennis *et all*., 1995) therefore, given the range of human hearing, the rate of sampling is considered 48,000 Hz. Then the digital signals will be stored on a computer hard disk using portable computer sound card, and installed CoolEdit 2000 software. Figure 4-A shows a sample of the audio signal in the time domain, but since the inspection and analyzing the emitted sound signals in time domain will determine limited information and considering the fact that the response of the ear and sense of sound in human depends highly on the frequency so it's necessary for sound signals in the time domain to be converted to the frequency domain until the frequency content of the sound signals are obtained (Crocker *et al.,* 1993). To convert time domain signals into the frequency domain, Fast Fourier Transform (FFT) method was used. Thus, a computer program was written to do this work and the frequency domain obtained using the narrow band noise spectrum. Figure 4-B shows an example of a sound signal in the frequency domain. By adding a sub computer program, frequency domain narrow band sound signals were converted to an overall sound level values.



Figure(4) A- noise signals in time domain, B- spectrum of the narrow-band sound pressure level at the driver's position, the speed 1700 rpm, and fuel composition E12.

3. Artificial Neural Networks

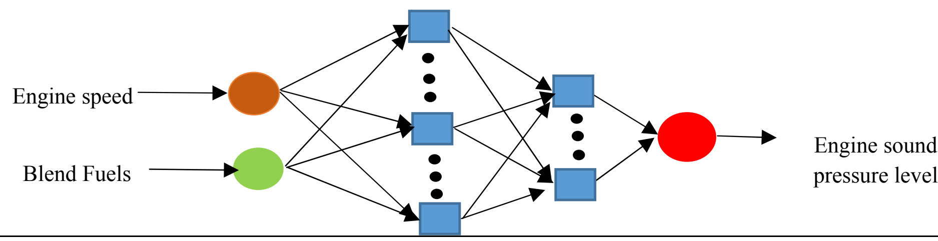
An artificial neural network consists of a number of neurons that are located together in a certain way. Neurons are located in layers and the network includes multiple neuron in the input layer, one or more neurons in theoutput layer and neurons in hidden layer or layers. Most artificial neural network algorithms and architectures alters by a change in the neuron model, and the connections between neurons that are used and applied weights between neurons. The most common type of artificial neural network, include feedforward, feedback and competitive (Fausett, 1993). In this study, feed forward neural networks were used. This type of neural network is mainly used for function approximation and models classification. Multi-layer Perceptron Network (MLP), is the most common feedforward network. The network consists of an input layer, one or more hidden layers and an output layer. To train the network, back-propagation error learning algorithm was used in which the process of applying this method is the following (Jam et all., 2000؛ Khanna, 1990) (A)- weight matrix randomly assigned to each of the connections (B)- Selecting the input vector and the corresponding output vector. (C)- Computing the outputs of the neurons in each layer and thus calculating the output neurons in the output layer D)- Weight update using back-propagation error method (E)- evaluating the performance of the trained network with the help of root mean square error (RMSE) and finally back to of section c and the end of the training.

3.1Artificial neural network topology

To calculate the overall sound level, training and evaluation of artificial neural networks, two different inputs including engine speed, and combinations of fuels were used. According to the conditions described in the previous section, artificial neural network with two neurons in the input layer (engine speed, various fuel blends) and an output layer neuron (overall sound level) were designed (Table 2). Figure 5 shows the topology of the neural network that has been used where the input and output parameters of the experiment are shown. In this study, we used the MATLAB R2013a software.

Table 2- Parameters affecting the level of the overall sound of the tractor engine.

Variable levels							**Variables**
E12D88	E10D90	E8D92	E6D94	E4D96	E2D98	E0D100	**Fuel blend**
2100	2000	1900		1800	1700		**Engine speed**



Figure(5) the used neural network topology.

To achieve good response, back propagation algorithm was used for training artificial neural network. Learning process by the above algorithm is an iterative process that involves changing the weights between different layers, which moves toward the stabilization of the weights in the training program, to minimize the error between the actual values and expectations. Given that one hidden layer is sufficient for solving function approximation problems (Fausett, 1993), in determining the best training algorithm, a hidden layer was used and the number of hidden layer neurons were obtained by trial and error. There are several training algorithms for propagation, among which the learning algorithmwith variable learning rate, Levenberg Marquardt, and gradient descent with momentum in estimating function problems that indicated better performance and presented and evaluated in this paper. For the purpose of training, the data were randomly divided into three parts in a way that 98 data for training, 21 data for testing the network and 21 data were used for network valuation. The average error rate for the training of multilayer perceptron networks with the back-propagation algorithm was tested with different topologies. Thus, the mentioned algorithm selected and optimized. After selecting the input and output data of the network, normalization, selecting training algorithms, actuator function, number of hidden layer neurons, number of hidden layers, number of repetitions (epoch), training parameter values and performance, training network using each of the algorithms, with a hidden layer and 5 neurons in the hidden layer, began, continued and increased to a maximum of 20 neurons. In this study, the performance function MSE was assigned 10^{-6}.

To find the best prediction, several neural networks were developed and trained with experimental data. To better evaluate the performance and selecting the optimal network, regression analysis and correlation coefficient was exerted between the network output and the desired output (experimental data) and the error obtained in this step was calculated. Optimal number of hidden neurons in training algorithms was determined based on the highest correlation coefficient and the lowest error. With an optimal number of neurons in the hidden layer, using error and trial method, you can determine the type of stimulus function, training parameters values and the number of intermediate layers which by better performance, the network would be selected as the optimal network. However the best network was detected based on the highest correlation coefficient in training stage, testing and evaluation, and the lowest error. The creation and selection of appropriate model to predict the overall sound pressure level with A weight scale in the other pass-by people situation is given in Figure 6.

4.Analysis of results

One of the problems in the training of neural networks is over-fitting. The over fitting is that after training the network, the error on the training set reaches its minimum value, but with the introduction of new data on the network, as inputs, the error is high. To prevent over fitting error due to the method of auto-tuning, early stopping technique was used. In this method, the available data were dividen into three subsets, 70% of data as training subset, 15% of data as validation subset and 15% as a subset of the experimental data, showed better results in reducing the model error. The number of hidden layer neurons was varied from 5 to 15 neurons that the optimal number for each training algorithm and MSE error is presented in Table (3). Figure (7) is related to training network procedure using the Levenberg-Marquardt and trainlm code. As can be seen, the network MSE error gradually decreased, and after 13epochs, the network training will be stopped with the message "Validation Stop", which represents the increase in the validation set error. Weights and biases are adapted according to the time when the error has been minimal. Similarity between test set error and the validation set shows the desired model results. In order to get more accurate evaluation of the model, regression analysis between the network outputs and the desired targets were assessed. The correlation coefficient obtained in the prediction of the overall sound pressure level with A weight scale at the other pass-by people 0.97784 position (Figure 8). Also with reviewing the experimental and predicted data for designed neural network, the maximum error ±0.6 dB was determined for 94/6% of data. The results indicate the high accuracy of artificial neural network after propagation, with two neurons in the input layer and one neuron in the output layer, in predicting the sound pressure level of the weighted scale A in other pass-by people position.

Table 3- Characteristics of the networks created.

MSE	R	number of neurons in the hidden layer	Training algorithm
0.080776	0.82445	13	Traingdx
0.08754	0.9285	13	Traingda
0.027237	0.97784	15	Trainlm
0.083531	0.9388	14	Trainscg

5.Conclusion

Due to the inappropriate effects of engine noise on tractor driver's health and pass-by people, accurate estimation of the overall received sound is important in selection of the engine speed variable values and different mixture of fuels. In this study a new method, independent of mathematical models, that would be smart to find the relationship between dependent and independent variables was applied and artificial neural networks were used as a way to nonlinear mapping. In a way that overall tractor sound level with two independent parameters of the engine speed and different fuel mixture was predicted. The results showed that Multilayer Perceptron Network with back-propagation learning algorithm and Marquardt learning rule, with two neurons in the input layer and one neuron in the output layer resulted in the lowest square mean error with value of (0.0272) and best correlation coefficient of (R=0.97784).

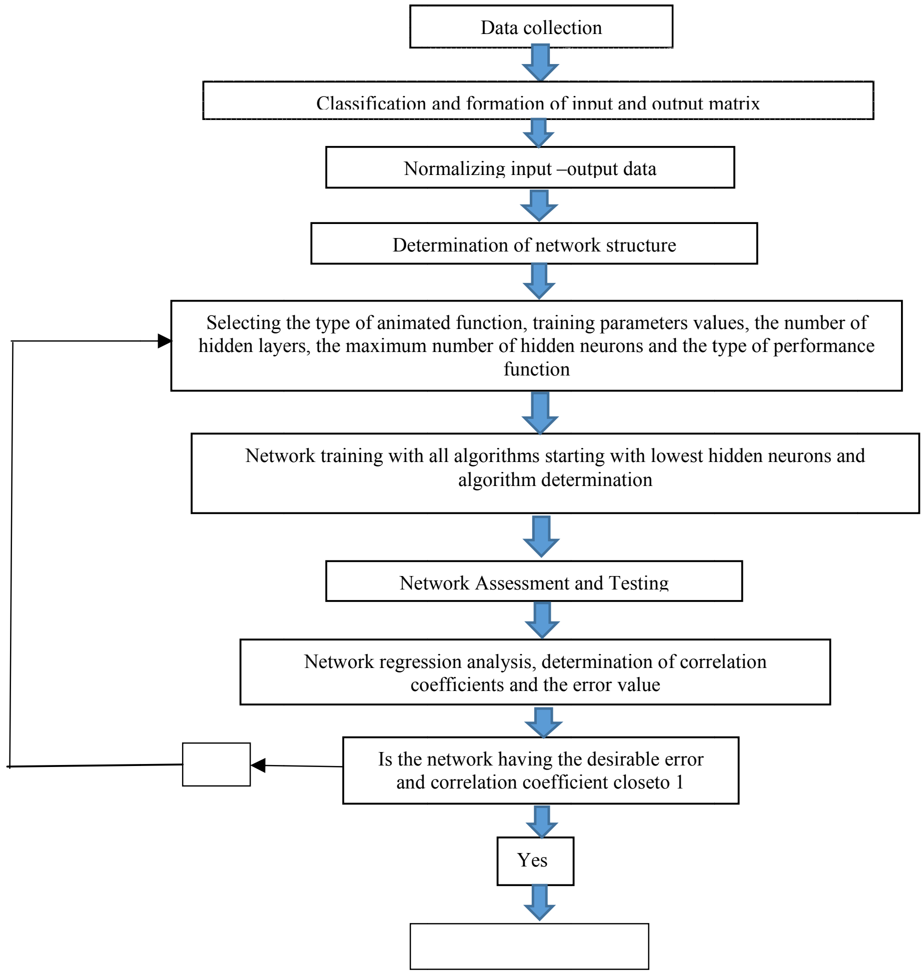
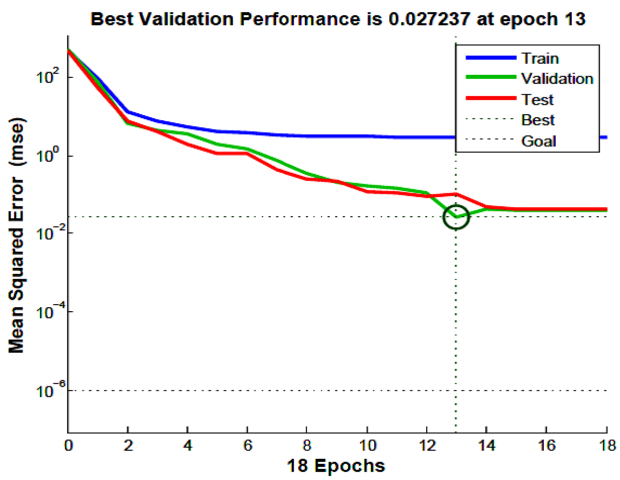
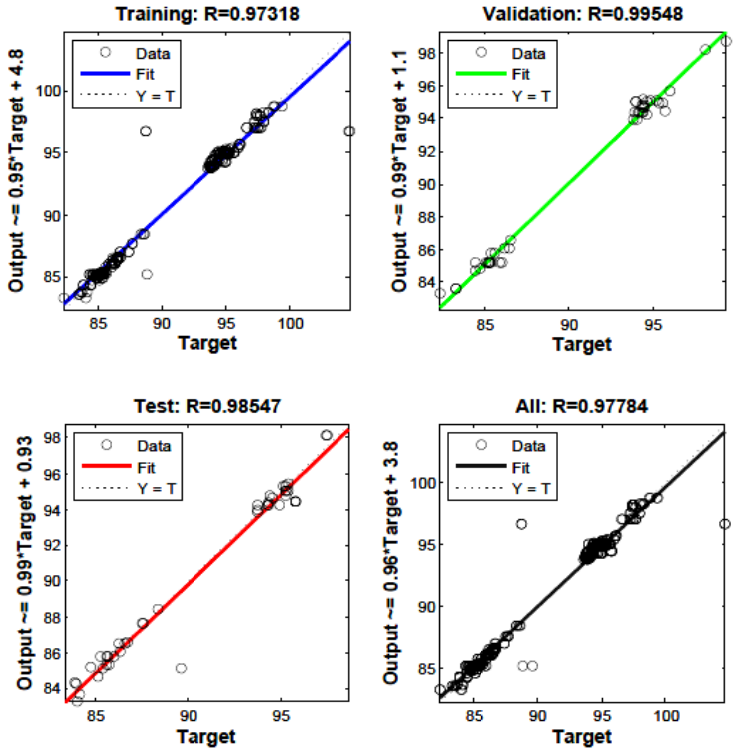


Figure (6) Steps to create and select the predicting overall sound pressure level model with A weight scale at other pass-by peopleposition.



Figure(7) variations in MSE error procedure using the Levenberg-Marquardt training network (Trainlm).



Figure(8) Regression analysisbetweenthe network outputandthe desired outputto predictthe overallsoundpressure levelwithA weightscaleinthe driversituation.

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