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RESEARCH ARTICLE

PREDICTION OF AGRICULTURAL TRACTOR NOISE LEVELS USING ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

Agricultural tractors generate noise pollution in the cabin and in open air. The demands for good sound comfort of the driver inside cabin and assistant driver in outside of these tractors are continuously growing. The main objective of this paper is to predict the noise levels surrounding the tractor operator and in open air by using Artificial Neural Networks (ANNs) and to compare the results against noise levels from collected data. The architecture of the network is used with the backpropagation algorithm - the multilayer feedforward networks. Another objective is to predict the tractor noise levels at various operating speeds and determine their influences on the surrounding noise. The use of a tractor may be avoided in the even its noise level exceeded safe levels. This can be actuated by a specific control system that selects the optimum speed generating safe noise levels.

INTRODUCTION

Noise at work in agriculture or horticulture can cause hearing loss. There are many different sources of noise on farms, such as tractors, chainsaws, livestock, grain dryers and guns. Noise can also be a safety hazard at work, interfering with communication and making warnings harder to hear. Noise is one of the most important environmental factors which affect the workers' health and efficiency. Noise can increase the overall workload of operators during a specific task and affect the performance. As a result, noise affects workers' health directly and indirectly [1]. Among these effects are weariness, backache, nervousness, nausea, careless, etc. [2-7]. The machines used in agricultural operations such as tractors, combines, shellers, driers, etc. expose noise of high level. More hearing loss is encountered among people who work in agricultural facilities than other jobs [8]. According to the test results and surveys made on farmers and agricultural workers, it was found that hearing loss occurs in people who are exposed to a sound pressure level of 84.8–86.8 dB(A) [9]. The agricultural tractors in the world, most of which have no cabins and hence operators have to work without noise insulation. However, there is no extended study on sound pressure levels occurring in agricultural machine applications.
Therefore it is important to study the influence noise levels occurring in tractors and agricultural machinery applications. Prediction of noise levels is necessary for determining the unsafe levels according to the world standards and trying to avoid the dangerous situations that might arise accordingly.

The main purposes of this study are;

- To predict the noise levels surrounding the tractor operator and in open air by using Artificial Neural Networks at different operating conditions.
- To predict the noise levels at various operating speeds, determine their harmful effects and avoid the use of a tractor in the event of unsafe levels of noise. Use of a special control system can help in reducing noise by selecting optimum tractor operating speeds.

The present paper makes benefit of using the results presented in the reference [10].

Actual Data and conditions

The actual data used for predicting the noise levels surrounding the tractor operator and in open air by using Artificial Neural Networks was collected from Ref. [10]. Celen and Arin, (2003) [10] determined the noise levels surrounding the tractor operator and in open air at two engine speeds (1000 and 2000 rpm), with strengthening gear and without strengthening gear and at reverse gear. Tables 1 and 2 show the actual results of the noise level at surrounding the tractor operator and in open air, respectively [10]. Figure 1 shows noise levels at the two selected engine speeds (1000 and 2000 rpm), with strengthening gear and without strengthening gear and at reverse gear. From the figure it is clear that the noise levels at the surrounding tractor operator were higher than the noise levels in open air. Figure 2 shows the maximum noise level at surrounding the tractor operator and in open air recorded for the first (a) and the fourth (b) transmission gear.

Artificial Neural Networks (ANNs)

Backpropagation was created by generalizing the Widrow-Hoff learning rule to multiple-layer networks and nonlinear differentiable transfer functions. Input vectors and the corresponding target vectors are used to train a network until it can approximate a function, associate input vectors with specific output vectors, or classify input vectors in an appropriate way as defined by the user. Networks with biases, a sigmoid layer, and a linear output layer are capable of approximating any function with a finite number of discontinuities. Standard backpropagation is a gradient descent algorithm, as is the Widrow-Hoff learning rule, in which the network weights are moved along the negative of the gradient of the performance function. The term *backpropagation* refers to the manner in which the gradient is computed for nonlinear multilayer networks. There are a number of variations on the basic algorithm that are based on other standard optimization techniques, such as conjugate gradient and Newton methods. The Neural Network Toolbox implements a number of these variations. Properly trained backpropagation networks tend to give reasonable answers when presented with inputs that they have never seen. Typically, a new input leads to an output similar to the correct output for input vectors used in training that are similar to the new input being presented. This generalization property makes it possible to train a network on a representative set of input/target pairs and get good results without training the network on all possible input/output pairs. There are two features of the Neural Network Toolbox that are designed to improve network generalization - regularization and early stopping [11].

Learning Backpropagation Algorithm

The method can be summarizing as follows [12]:

1- Apply the input vector, $x_p = (x_{p1}, x_{p2}, \ldots, x_{pn})^t$ to the input units.

2- Calculate the net-input values to the hidden layer units:

$$net^h_{pj} = \sum_{i=1}^{N} w^h_{ji} x_{pi} + \theta^h_j \tag{1}$$

Where w^h_{ji} = the weight on the connection from the i^{th} input unit, and θ^h_j the bias term. The "***h***" superscript refers to quantities on the hidden layer.

3- Calculate the output from the hidden layer:

$$i_{pj} = f^h_j \left(net^h_{pj} \right) \tag{2}$$

4- Move to the output layer. Calculate the net-input values to each unit:

$$net^h_{pk} = \sum_{j=1}^{L} w^o_{ki} x_{pj} + \theta^o_k \tag{3}$$

5- Calculate the outputs:

$$o_{pk} = f^o_k \left(net^o_{pk} \right) \tag{4}$$

Where: "***o***" superscript refers to quantities on the output layer.

6- Calculate the error terms for the output units:

$$e^o_{pk} = \left(y_{pk} - o_{pk} \right) f^{o'}_k \left(net^o_{pk} \right) \tag{5}$$

Where: subscript "*p*" refers to the *p*th training vector, and "*k*" refers to the k^{th} the output unit. In this case, y_{pk} is desired output value, and O_{pk} is the actual output from the k^{th} the unit.

When linear output function use:

$$f^o_k \left(net^o_{jk} \right) = net^o_{jk} \tag{6}$$

$$f^{o'}_k = 1 \tag{7}$$

When sigmoid output function use:

$$f^o_k \left(net^o_{jk} \right) = \left(1 + e^{-net^o_{jk}} \right)^{-1} \tag{8}$$

$$f^{o'}_k = f^o_k \left(1 - f^o_k \right) \tag{9}$$

7- Calculate the error terms for the hidden units:

$$e^h_{pj} = f^{h'}_j \left(net^h_{pj} \right) \sum e^h_{pk} w^o_{kj} \tag{10}$$

Notice that the error terms on the hidden units are calculated before the connection weights to the output-layer units have been updated.

8- Update weights on the output layer:

$$w^o_{kj}(t+1) = w^o_{kj}(t) + \eta e^o_{pk} i_{pj} \tag{11}$$

The factor η is called the learning-rate parameter.

9- Update weights on the hidden layer:

$$w^h_{ji}(t+1) = w^h_{ji}(t) + \eta e^h_{pj} x_i \tag{12}$$

The order of the weight updates on an individual layer is not important.

Be sure to calculate the error term

$$E_p = \frac{1}{2} \sum_{k=1}^{M} e^2_{pk} \tag{13}$$

Since this quantity is measure of how well the network is learning. When the error is acceptable small for each of the training-vector pairs, training can be discontinued.

Neural network simulation

To simulate the neural network, the backpropagation training functions in the MATLAB toolbox were used [11]. The architecture of the network is most commonly used with the backpropagation algorithm - the multilayer feedforward networks. Feedforward networks often have one or more hidden layers of sigmoid neurons followed by an output layer of linear neurons. Multiple layers of neurons with nonlinear transfer functions allow the network to learn nonlinear and linear relationships between input and output vectors. Multilayer networks often use the log-sigmoid transfer function *"logsig"*. The function *"logsig"* generates outputs between 0 and 1 as the neuron's net input goes from negative to positive infinity. Occasionally, the linear transfer function *"purelin"* is used in back propagation networks, (Figure 3) [11]. The input layer of the model consisted of four nodes corresponding to four input variables; 1- location, 2- engine speed, 3- strengthening gear and 4- gear shift. The output consisted of one node namely the noise level.

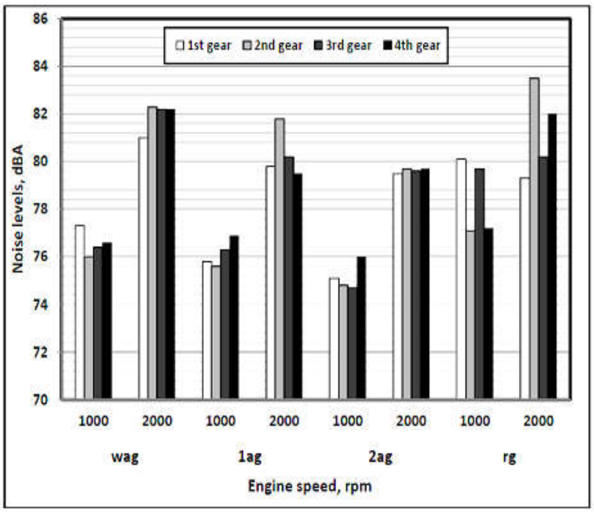
Two engine speeds (1000 and 2000 rpm) on four cases of strengthening gears, without strengthening gear, 1st strengthening gear, 2nd strengthening gear and Reverse gear with four gear shifts (1st gear, 2nd gear, 3rd gear and 4th gear) at two locations (surrounding the tractor operator and open air) are used. To increase the precision and velocity of ANN process, all data were normalized by the following relationship:

Table 1: Measured noise level at surrounding the tractor operator [10].

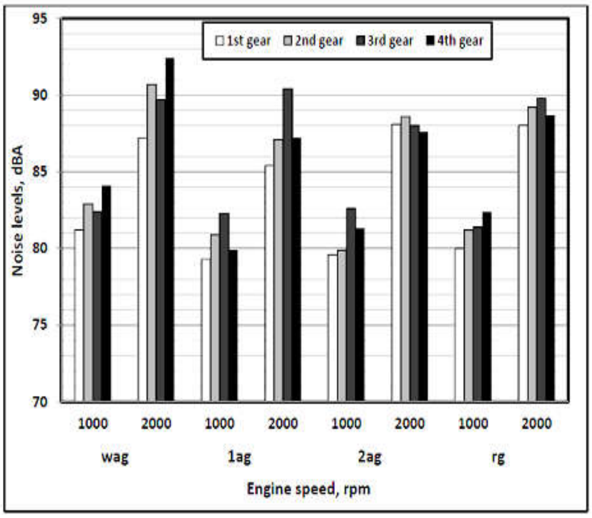
Strengthening gear	Noise levels, dBA							
	Engine speed, rpm							
	1000				2000			
	Gear Shift							
	1st gear	2nd gear	3rd gear	4th gear	1st gear	2nd gear	3rd gear	4th gear
Without strengthening gear	81.2	82.9	82.4	84.1	87.2	90.7	89.7	92.4
1st strengthening gear	79.3	80.9	82.3	79.9	85.4	87.1	90.4	87.2
2nd strengthening gear	79.6	79.9	82.6	81.3	88.1	88.6	88	87.6
Reverse gear	80	81.2	81.4	82.4	88	89.2	89.8	88.7

Table 2: Measured noise level in open air [10].

Strengthening gear	Noise levels, dBA							
	Engine speed, rpm							
	1000				2000			
	Gear Shift							
	1st gear	2nd gear	3rd gear	4th gear	1st gear	2nd gear	3rd gear	4th gear
Without strengthening gear	77.3	76	76.4	76.6	81	82.3	82.2	82.2
1st strengthening gear	75.8	75.6	76.3	76.9	79.8	81.8	80.2	79.5
2nd strengthening gear	75.1	74.8	74.7	76	79.5	79.7	79.6	79.7
Reverse gear	80.1	77.1	79.7	77.2	79.3	83.5	80.2	82

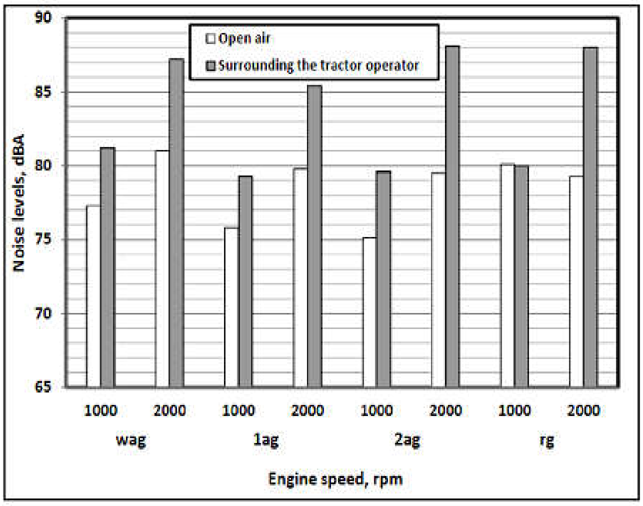


(a) Open air

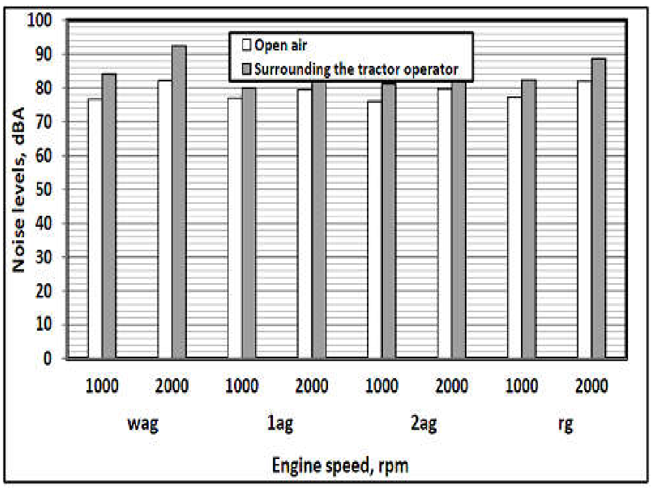


(b) Surrounding the tractor operator

Figure 1. Maximum noise levels at engine speeds 1000 and 2000 rpm 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear [10]



(a) 1st gear



(b) 4th gear

Figure 2. Maximum noise level at 1000 and 2000 rpm engine speed, at surrounding the tractor operator and in open air;; 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear [10]

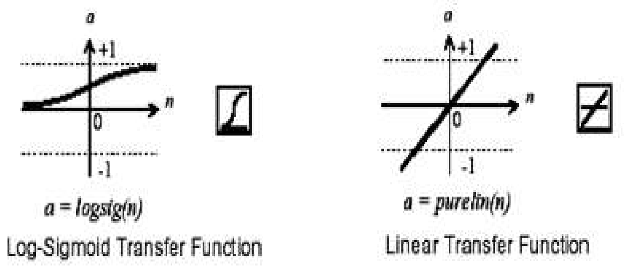


Figure 3. The log-sigmoid and linear transfer functions [11]

$$X_n = \frac{X_i - X_{min}}{X_{max} - X_{min}} \qquad (14)$$

Where,

X_n = normalized value
X_i = actual value
X_{min} = minimum of actual value
X_{max} = maximum of actual value

Several fully connected architectures were experimented so as select the final appropriate network configuration for this application. The network with two hidden layers, 4-500-250-1, converged faster than the other since it could map more significant input patterns (refer to Figure 4) into related output. The network was trained until convergence of the measured output and the predicted output after 240 epochs is obtained. The training was then stopped when the total sum of square errors reached its minimum value of 8.62669×10^{-7}; this is shown by Figure 5.

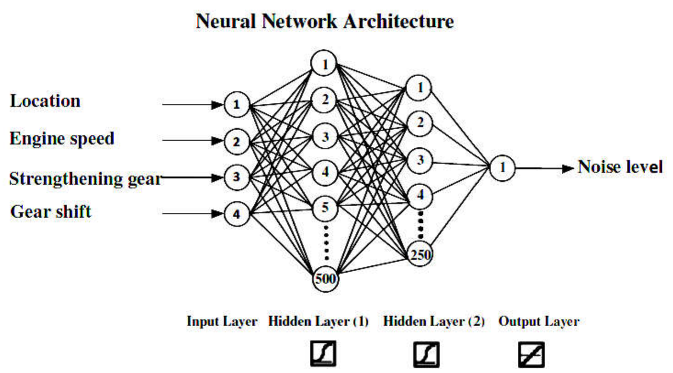


Figure 4. Architecture for the 4-500-250-1 neural showing input and output parameters and two hidden layers for predicting noise levels surrounding the tractor operator and in the open air

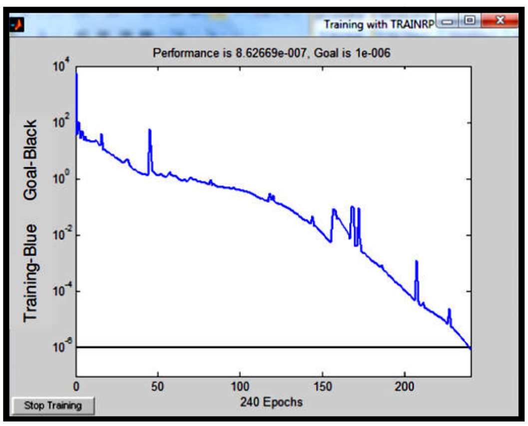


Figure 5. Neural network (4-500-250-1) training the noise levels showing the total sum of the square errors at different stages of training (epochs)

Simulation Results

Comparison of actual results against the results obtained by neural network output (the noise levels surrounding the tractor operator and in open air) at two engine speeds (1000 and 2000 rpm) at surrounding the tractor operator and in open air are demonstrated in Figures 6 to 9.The neural network model can be used with sufficient accuracy to compare the actual results gained by measurements of noise level against the output of the neural network model for each variable of all inputs.

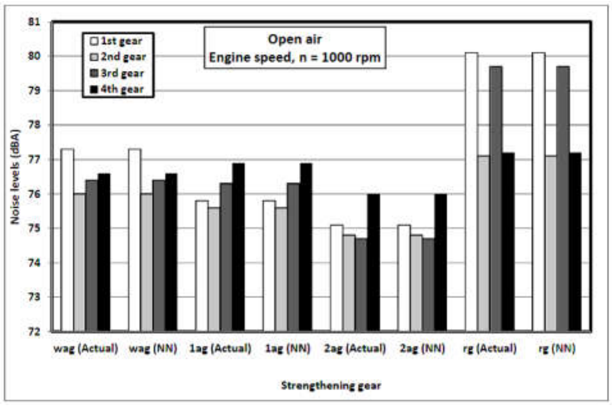


Figure 6. Noise level at 1000 rpm tractor engine speed in open air for the transmission gears

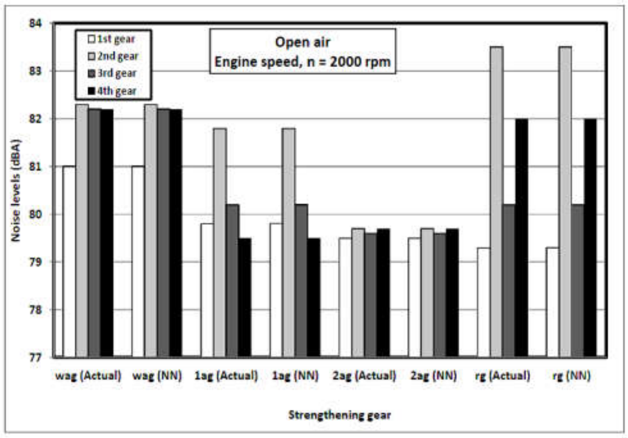


Figure 7. Noise level at 2000 rpm tractor engine speed in open air for the transmission gears

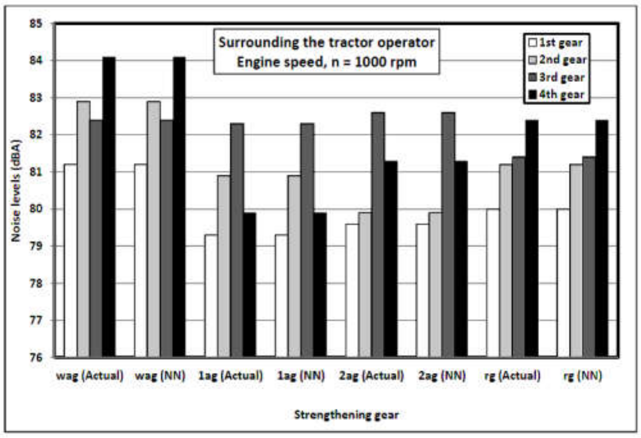


Figure 8. Noise level at 1000 rpm engine speed at surrounding the tractor operator for the transmission gears

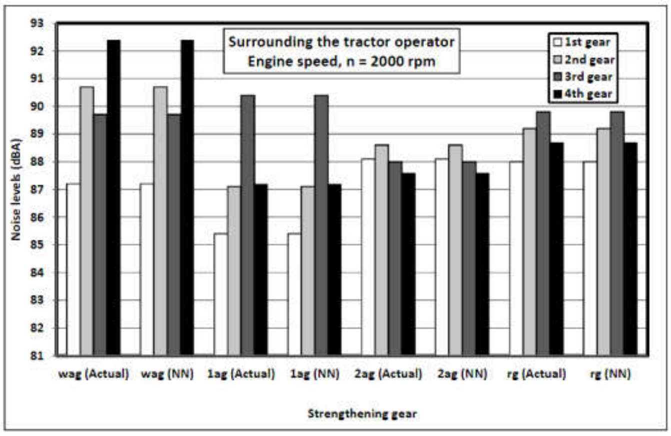
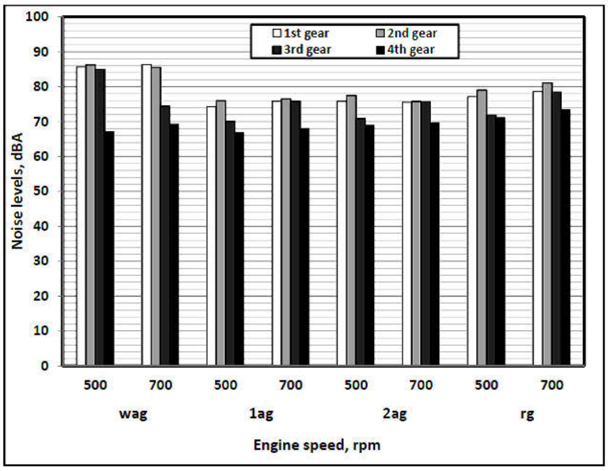
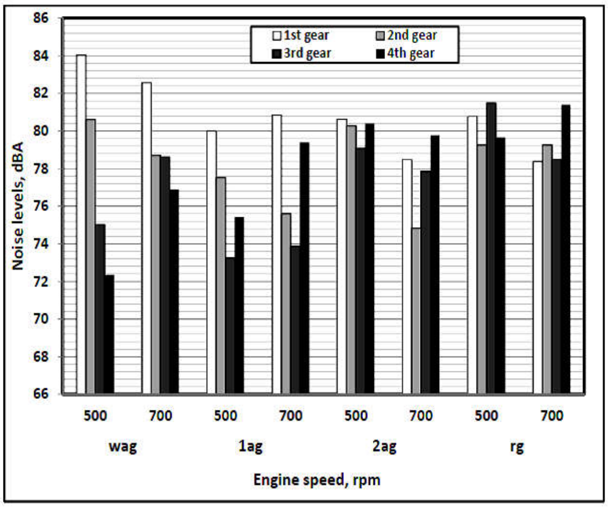


Figure 9. Noise level at 2000 rpm engine speed at surrounding the tractor operator for the transmission gears

Additional engine speeds of 500 and 700 rpm (under range), 1400 and 1800 rpm (between range), and 2400 and 2800 rpm (over range) were used to test the generalization ability of the network model are shown in Figs. 10 to 15. The network accurately predicted the noise level for all tested engine speeds (training data) and for additional speeds as well.

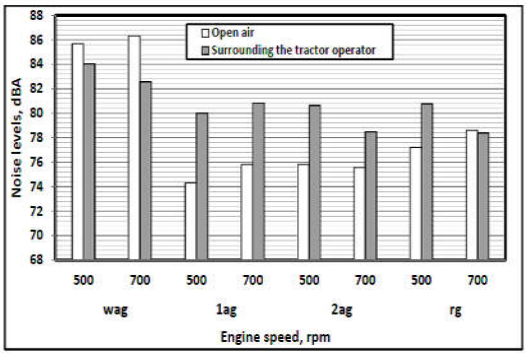


(a) Open air

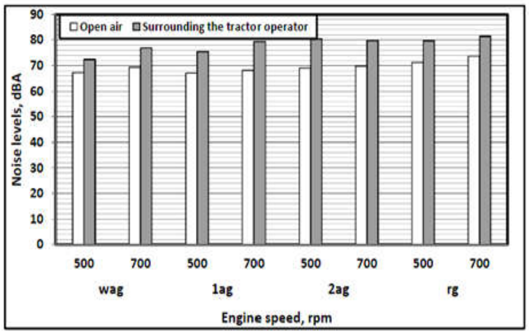


(b) Surrounding the tractor operator

Figure 10. Maximum noise levels at new engine speeds of under range (500 and 700 rpm); 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear

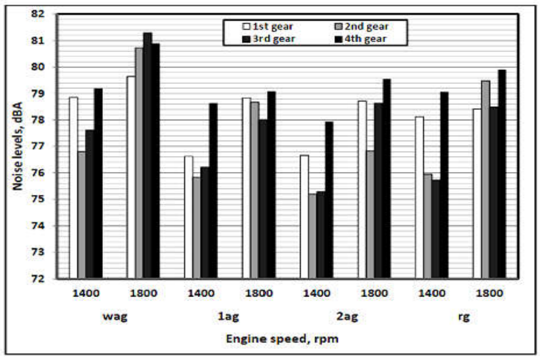


(a) 1st gear

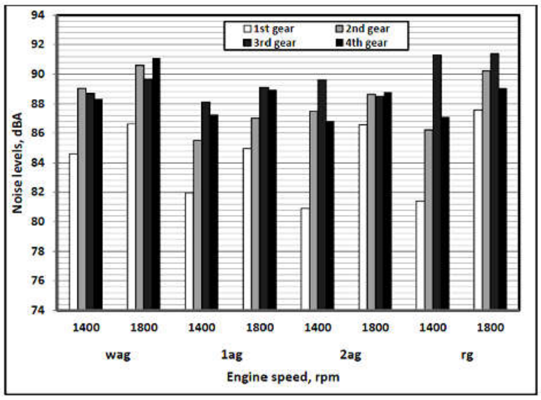


(b) 4th gear

Figure 11. Maximum noise level at engine speeds of under range (500 and 700 rpm), at surrounding the tractor operator and in open air;; 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear

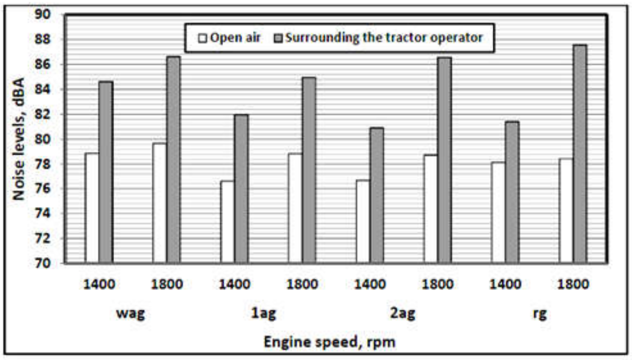


(a) Open air

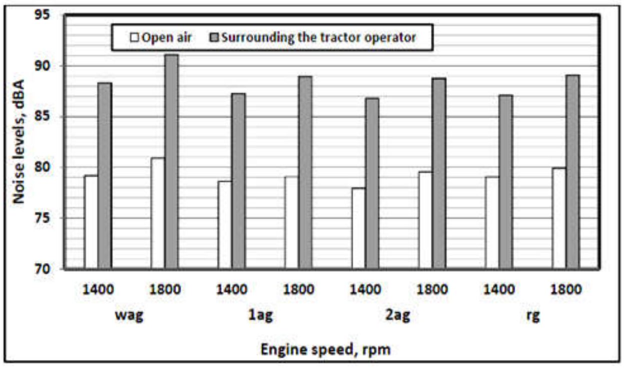


(b) Surrounding the tractor operator

Figure 12. Maximum noise levels at engine speeds between range (1400 and 1800 rpm); 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear

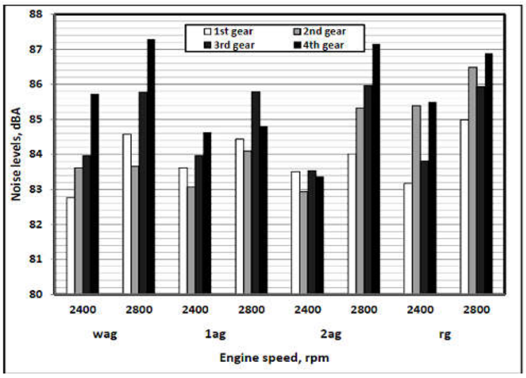


(a) 1st gear

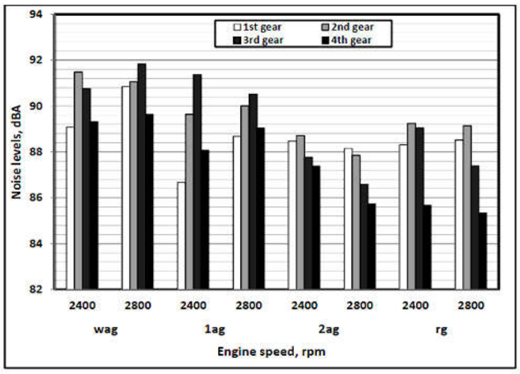


(b) 4th gear

Figure 13. Maximum noise level at engine speeds of between range (1400 and 1800 rpm), at surrounding the tractor operator and in open air; 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear

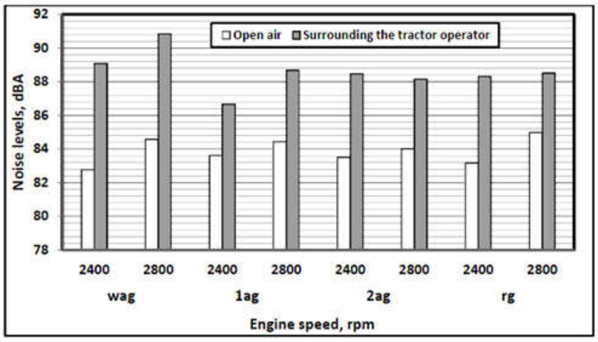


(a) Open air

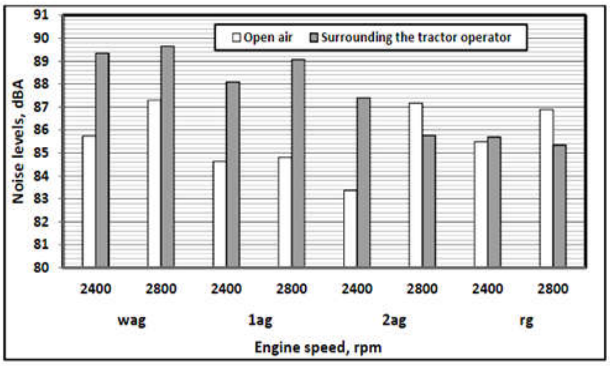


(b) Surrounding the tractor operator

Figure 14. (a) at open air, (b) at surrounding the tractor operator, determined maximum noise levels at a new engine speeds of over range (2400 and 2800 rpm); 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear



(a) 1st gear



(b) 4th gear

Figure 15. Maximum noise level at engine speeds of over range (2400 and 2800 rpm), at surrounding the tractor operator and in open air;; 1ag, 1st strengthening gear; 2ag, 2nd strengthening gear; wag, without strengthening gear; rg, at reverse gear

Conclusion

- Use of neural network technique is useful for predicting the noise generated by tractor operation both in confined space around tractor operator and in open air around the tractor.
- Neural network technique also enables predicting the noise generated by the tractor operation at different speeds other than obtained by direct measurements; this contributes to time and cost saving.
- Survey of recent researches related to tractor noise showed that there are no mathematical relationships that can be used for tractor noise prediction.
- Neural network technique can also be used in controlling the noise level by operating the tractors on speeds that generate lower noise levels without sacrificing tractor performance.

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