

Prediction of the Sound Absorption Performance of Polymer Wool by Using Artificial Neural Networks Model

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ABSTRACT

This paper proposes a new method of predicting the sound absorption performance of polymer wool using artificial neural networks (ANN) model. Some important parameters of the proposed model have been adjusted to best fit the non-linear relationship between the input data and output data. What's more, the commonly used multiple non-linear regression model is built to compare with ANN model in this study. Measurements of the sound absorption coefficient of polymer wool based on transfer function method are also performed to determine the sound absorption performance according to GB/T18696. 2-2002 and ISO10534- 2: 1998 (E) standards. It is founded that predictions of the new model are in good agreement with the experiment results.

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INTRODUCTION

Nowadays vehicle noise has become one of the resources of pollution that do harm to people's health and environment. The applications of various sound packaging materials in practice have become one of the important and effective methods to control and reduce noise. Thus, great attention has been paid to researches on the sound absorption performance of these materials in sound package field. It is well acknowledged that accurate prediction of the sound absorption performance of sound packaging materials can provide great benefit required for these materials to be applied in vehicle industry.

There have been numerous studies and researchers have proposed many methods to predict the sound absorption coefficient of the material since the past several decades. And most of current predicting methods are based on theoretical models with some known parameters of materials such as pore geometry, frequency, air flow resistivity, etc. Probably the most famous model is Delaney and Bazley model [1]. Delaney and Bazley studied the acoustical property of fibrous materials and presented empirical power-law relationships between the ratio of frequency to air flow resistivity, the characteristic impedance and the propagation constant through regression analysis. Wu [2] extended the range of applications for the model using more samples of porous plastic open-cell foam, thus covering a wider airflow resistivity range. Garai, et al [3] developed a new empirical model for polyurethane foam according to Delaney and Bazley's result. Voronina [4] derived the characteristic impedance and propagation constant as functions of the fibre diameter and porosity through comparative analysis, while Bies

and Hansen [5] built a polynomial description of the characteristic impedance and propagation constant. Unlike the empirical model above, Johnson and Allard, et al [6-7] built a microstructural model that involves the five important parameters: the flow resistivity, porosity, tortuosity and two characteristic lengths. These traditional methods, to some extent, are playing an important role in estimating the sound absorption coefficient of materials. However, recent years have witnessed artificial neural networks to be widely used in academic research, for it offers high accuracy performance of predicting patterns.

Artificial neural network has been increasingly used since it was discovered over 50 years ago. Especially in recent 20 years, it has enjoyed widespread use in medicine, mathematics, engineering, economics and many other fields. It is usually used to analyze complex data, recognize pattern and sound, forecast weather and market trend, identify target in military and predict data in engineering field and realm of academic [8]. The major advantage of this approach over traditional model method lies on the facts that it can adapt easily to different types of data formats and configurations and address problems that are complex and intractable.

Therefore, considerable studies have been focused on ANN because of its powerful capability of dealing with linear and non-linear relationship problems. Turan, et al [9] used an ANN model based classification technique to predict the percentage adsorption efficiency for the removal of Zn (II) ions from leachate by hazelnut shell. Chokmani, et al [10] made prediction studies by ANN models in hydrology field. Kalogirou

[13] and Balabin [14] applied ANN models into energy research. With a developed ANN model, Zhang, et al [15] investigated the bankruptcy in economy and Caocci [16] employed it in medical field. In other studies, Gardner, et al. [17] predicted acoustic properties of polyurethane foam, while Lin, et al [18] estimated the sound absorption coefficient of perforated wooden panels with ANN model.

The aim of this paper is to apply artificial neural networks model into vehicle sound package field. An artificial neural networks model is developed to predict the sound absorption coefficient for polymer wool. The model is not only quite simple but also can estimate the sound absorbing performance of polymer wool accurately in all frequency bands.

ARTIFICIAL NEURAL NETWORK (ANN)

Artificial neural network is a mathematical computational model whose architecture and working principle is extremely like human brain system. As a system, it has three significant features: non-linear, the ability to adaptive control, self-learning capability. As the research moves along, there have been more than 40 kinds of artificial neural networks so far. Also, the most popular neural network is back-propagation (BP) network [19], which is also adopted in this research.

An artificial neural network [19] is a network of numerous interconnected simple processing units called neurons or nodes. Each neuron in a layer, which has no relations with other neurons in the same layer, is interconnected with all neurons in the preceding and following layer. A neuron typically includes numerous input variables, each of which has a corresponding weight. The neuron takes a weighted sum of input variables plus a bias and passed through the summation to an activation function to generate an output, which is passed on to next neuron in following layer, as presented in Fig. 1 where x_i and y_j are the input and output variables; w_{ij} is corresponding weighted value; θ_j is the bias; s_j is the weighted summation and $f(s_j)$ is the activation function. Generally, a lot of neurons or nodes are arranged in a column or group which is called a layer. As shown in Fig. 2, a commonly used ANN is comprised of an input layer, at least one hidden layer and an output layer.

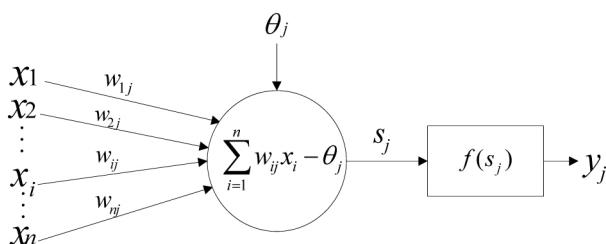


Fig. 1. Structure of a neuron

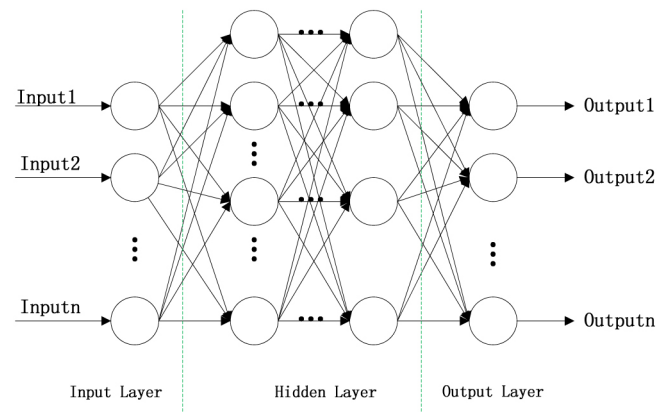


Fig. 2. Typical architecture of the ANN

A complete ANN model is typically made up of two steps: training network process and testing network process.

During the training step, the input data are presented to the input layer and passed through the hidden layer to the output layer in the end. The input values are weighted and summed at each neuron in hidden layer. The weighted sum is passed on to the neuron's activation value through a proper transfer function. The value then turns into an input of a neuron in the output layer. At last an output is generated in the same way through another transfer function. Two commonly used transfer functions in this process are the linear function and the sigmoid function, as expressed in Eqs. (1)-(2).

$$f(x) = ax \quad (1)$$

$$f(x) = \frac{1}{1+e^x} \quad (2)$$

where x is the independent variable and a is the coefficient.

Virtually the aim of the training process is to determine the weight and bias. At this step, the network is adjusting the weight and bias to obtain the goal that the predicted outputs best agree with the target values. However, long period time of training may cause some concerned problems such as overtraining. When overtraining occurs, the network has memorized the detailed information about the training examples, but it has not learnt to generalize to new situations. Apparently this so-called overtraining phenomenon can lead to the loss of the network's generation ability. To avoid this, the data available are divided into three sets: the learning set, the validation set and the testing set. The learning set is employed to compute and adjust the weights and bias. The validation set is used to avoid the overtraining of the neural network by monitoring the validation error between the outputs and desired targets during the training process. The training process will be stopped early when the validation error reaches an acceptable

level or will begin to increase due to the overtraining problem. And the neural network weights corresponding to the minimum validation error will be maintained.

Both of the learning set and the validation set are used in the training step. However, the testing set, which is independent to the learning set and the validation set, is utilized in the testing step. Once the objective of minimizing the error of the predicted outputs and the target values is achieved, the ANN model has been completely built, which then can be used to predict pattern. That is the testing process. The complete predicting process of ANN model is illustrated in Fig. 3.

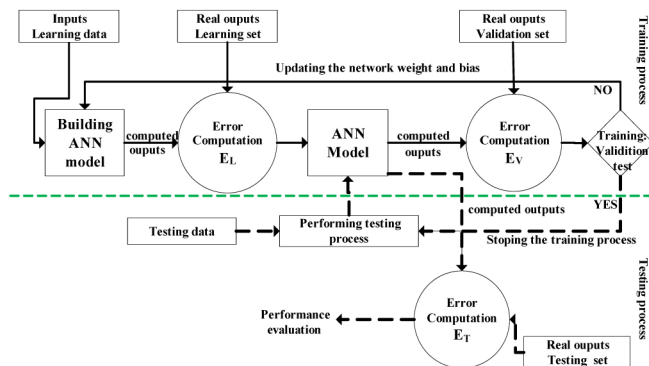


Fig. 3. Complete predicting process of the ANN model

MATERIAL AND EXPERIMENT

The polymer wool used in this paper is made of polyester and polypropylene, whose air flow resistivity is measured carefully and accurately by experiment. The samples with diameters of 100mm and 28mm have the identical thickness for measurement, as shown in Fig. 4. The impedance tube made by SCS Corporation for the transfer function method was employed to measure the sound absorption coefficient of the wool. The schematic diagram of the transfer function method is presented in Fig. 5. The SCS impedance tube includes two different tubes. One with diameters of 100mm is used to measure the sound absorption coefficient in low frequency band from 63Hz to 2000Hz. The other with diameters of 28mm is applied to measure the sound absorption coefficient in high frequency band from 800Hz to 6300Hz, as shown in Fig. 6. The measurements were conducted according to GB/T18696. 2-2002 and ISO10534- 2: 1998 (E) standards at 15 °C and 30% relative humidity.



Fig. 4. Parts of the material samples

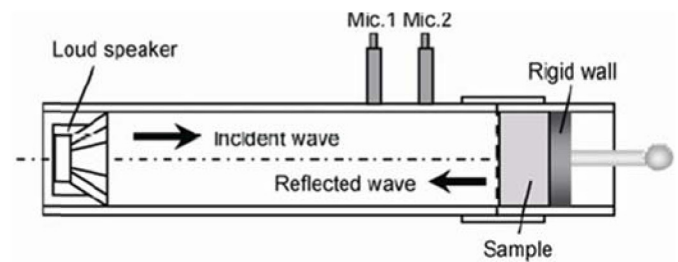


Fig. 5. Schematic diagram of the transfer function method



Fig. 6. Impedance tube by the transfer function method

ARTIFICIAL NEURAL NETWORK MODEL (ANN)

As a robust and efficient procedure, the back-propagation (BP) network has been becoming the most widely used ANN model, which is employed to predict the sound absorbing performance in this article.

Parameters and Functions Determination

The air flow resistivity of the material has been measured directly through experiment and the frequency is a known parameter. Both of them are determined as the input parameters, while the output parameter is the sound absorption coefficient.

The logsig function, which is a differentiable function, can map a random number to a value that ranges from 0 to 1. In this paper, the input parameters are tremendously big, while the output parameter, the sound absorption coefficient, varies from 0 to 1. The non-linear relation between the inputs and outputs are quite complicated, and the logsig function can make it easy to converge for this model. So it is chosen as the hidden layer transfer function. The output layer function is set as purelin function, for it is linear, which is easy and quick to perform. The training function is determined as trainbfg, which has the advantage of fast rate of convergence.

Datasets Classification

According to different sample thickness and air cavity depth, the materials available are divided into 6 cases, as listed in Table 1. In each case, there are seven groups of materials with different values of air flow resistivity. Twenty frequency records in every group are selected from the frequency bands as the input variable. Therefore, there are 140 (20*7) records of data in total to use for the model in every case. All the data in every