Available online at www.sciencedirect.com
ScienceDirect
Simulation Modelling Practice and Theory 16 (2008) 410–418
SIMULATION MODELLING PRACTICE AND THEORY
www.elsevier.com/locate/simpat

Sound quality analysis of cars using hybrid neural networks

Şahin Yıldırım *, İkbal Eski

Erciyes University, Engineering Faculty, Mechanical Engineering Department, Machine Theory and Dynamics Research Lab, 38039 Kayseri, Turkey

Received 18 April 2006; received in revised form 12 September 2007; accepted 14 January 2008
Available online 26 January 2008

Abstract

In this paper, a procedure of testing and evaluation on the sound quality of cars are proposed and sound quality is analysed through the cars' road running test on the providing ground, which was carried out with varying running speed. In addition to this experimental analysis, a neural network predictor is also designed to model the system for possible experimental applications. The proposed neural network is a recurrent type network, which consists of two types of neuron function in the hidden layer. As basic factors for sound quality, only objective factors are considered such as loudness, sharpness, speech intelligibility, and sound pressure level. The correlation between sound pressure level and another factor are discussed from a point of view of running speed dependency. Results of both computer simulations and experiments show that the neural predictor algorithm gives good results at accommodating different cases and provides superior prediction on two cars' sound analysis.

Keywords: Cars; Neural network; Sound pressure; Loudness; Sharpness; Running speed

1. Introduction

Recently, sound quality is becoming the major concern of acoustic problem in cars. Many studies about this have been investigated, but the requirement of improving sound quality of passenger cars are increasing [1,2]. To improve the sound quality in passenger cars, many noise sources must be considered and human feeling to the noise also must be taken into account.

Reducing noise and vibration has long been an aim for the development engineer, and in many cases, levels have been reduced so that many products report very similar results. It is now becoming clear that it is not just level that counts, but also the quality of the sound from the machine. Is it rough? Does it sound tinny? Does it rattle? These issues have been identified by the automotive industry years ago, and now the sound of a car is as important as the trim level, or even performance. Driving a car is a combination of sensations, of which the sound quality is becoming more important. Although many acoustic problems on the cars have been solved, more efforts are required in the field of sound quality. It should be said that the mind of sound quality is not

* Corresponding author. Tel.: +90 352 4374901.
E-mail address: sahiny@erciyes.edu.tr (Ş. Yıldırım).

1569-190X/$ - see front matter © 2008 Elsevier B.V. All rights reserved.
doi:10.1016/j.simpat.2008.01.002

Nomenclature

Notation

$\mathbf{F}\{\}$	activation function of neurons in non-linear hidden layer
HT	hyperbolic tangent function
$\mathbf{I}$	$n_{H1} \times n_{H1}$ identity matrix
$\mathbf{J}_1$ and $\mathbf{J}_2$	$n_{H1} \times n_O$ and $n_{H2} \times n_O$ matrices with all elements equal to 1
n_H	number of neurons in hidden layer
Ntr	number of training iterations
n_{H1} and n_{H2}	numbers of linear and non-linear hidden neurons
n_O	number of output neurons
$\mathbf{V}(t)$	input to a recurrent hybrid network
$\mathbf{W}^{H1}$	matrix of weights of connections between linear hidden layer and output layer
$\mathbf{W}^{H2}$	matrix of weights of connections between non-linear hidden layer and output layer
$\mathbf{W}^{I1}$	matrix of weights of connections between input layer and linear hidden layer
$\mathbf{W}^{I2}$	matrix of weights of connections between input layer and non-linear hidden layer
$\mathbf{x}_1(t)$	output of linear part of hidden layer
$\mathbf{x}_2(t)$	output of non-linear part of hidden layer
$\mathbf{N(t)}$	output of network
α	feedback gain
β	self-feedback gain
η	learning rate
μ	momentum coefficient

actually applied to the passenger vehicles interior noise. For the acoustics of automotive, especially in passenger vehicles, the sound quality of interior noise could be appointed as a major factor for classifying quality of productions.

Statistical treatments have been applied to sound quality analysis, and many researches of identifications on the sound quality factors using intelligent engineering technology have been tried [1]. In their investigation, car interior and roughness level have been reduced theoretically.

Because most of the acoustic problems for automotive accoutred after the design and manufacturing stages as a result, in many cases, absorbing and insulting sound after the trial error method was widely applied. It could be an actual approach in effect. But the sound quality problem may not be overcome by the absorbing and insulting. It may have a possibility to include more serious and sensitive factors in structural consideration. Especially in the case of sound quality, more correct prediction and analysis was required, and more careful research was indeed on the troubleshooting [2]. They have reduced the sound of car interior by using an evaluation method. Another investigation was the evaluation of the ability of active noise control systems to achieve a more pleasant sound by means of sound quality analysis of a real multi-channel active noise controller. The sound quality study has focused on the estimation of noise quality changes through the evaluation of the sense of comfort. Two methods have been developed: firstly, a predictive method based on psychoacoustic parameters (loudness, roughness, tonality and sharpness); and secondly, a subjective method using a jury test. Both results have been related to the spectral characteristics of the sounds before and after active control. It can be concluded from both analyses that active noise control positively affects acoustic comfort. Finally, from what has been shown, it can be said that the subjective improvements strongly depend on the attenuation level achieved by the active noise control system operation, as well as the spectral characteristics of the sounds before and after control [3].

Nor et al. have studied to evaluate vehicle comfort index according to the most frequently used sound quality metrics, namely, Zwicker loudness, sharpness, roughness and fluctuation strength.

As a result, researchers of different fields of automotive acoustics investigations can use this index according to the type of road (international road roughness) without any need to perform time-consuming jury tests. The