Sound Quality Evaluation on Interior Noise in High-speed Trains

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Abstract

Sound quality is one of the key factors influencing the comfort of passengers in high-speed trains. The prediction on sound quality evaluation is necessary if we want to know how people feel in the train without taking subjective tests all the time, which are time consuming. 32 recorded sound samples inside the cabins of high-speed train have been analyzed. Psychoacoustic properties, such as loudness, sharpness, roughness etc. and together with A-weighting sound pressure level (SPL) were calculated. A subjective evaluation has been conducted, in which subjects were asked to listen to the sound samples and rate using the rating scales method. A neural network was trained and established using the calculated psychoacoustic properties as inputs through the determination of psychoacoustic properties calculation methods while the subjective rating results as output. The aim of the network is to predict the human's perception on the interior noise in high-speed trains, allowing to predict the acoustical environment. In this paper, the sound quality evaluation methods and the neural network prediction model are presented together with the prediction results discussed.

Introduction

With the rapid development of high-speed trains, the speed is on a fast increase, leading to unavoidable noise problems. The SPL has been reduced to an acceptable level but it does not basically solve the noise problem. Sound quality, which describes how human feel about what they hear, is important besides the SPL [1]. Psychoacoustic properties and subjective tests are two ways to evaluate sound quality, among which subjective tests are directly related to human perception, so it is what people care. But the tests are quite time-consuming and complicated, therefore a prediction method is necessary [2]. This paper gives a way to predict the human perception for interior noise of high-speed train by using neural network. Besides the establishment of neural network, optimal calculation methods for loudness and sharpness are selected among different combination options.

Interior Noise Evaluation

The recording measurements were conducted in CRH380B—which is the first high-speed train in extremely cold areas in China. The dummy head was placed in different positions to record interior noise in different situations—different speeds, road surroundings etc. Then 32 sound samples with 5 seconds duration for each were extracted from the recordings. Each sample is chosen as different from others as possible.

Psychoacoustic Properties Calculation

Loudness, sharpness, roughness, tonality, fluctuation strength, articulate index (AI) and speech intelligibility index are calculated for each sound sample, as well as A-weighting SPL. Among them loudness and sharpness have more than one calculation method, leading to different calculation results. So for all the properties, there are totally 13 groups of calculation results due to different calculation method combinations.

Subjective Evaluation

With equal-loudness process, the sound samples are used for subjective evaluation. 32 subjects (23 males, 9 females) without acoustic knowledge are chosen to do the evaluation by using the rating scales method in hemi-anechoic chamber [3]. Table 1 is the rating scales for the subjects.

With Spearman correlation analysis for the subjective evaluation results, 6 subjects whose correlation coefficients are less than 0.6 are eliminated.

Take the Spearman correlation analysis between the psychoacoustic properties calculation results and subjective evaluation rating and then two-sided test is conducted. Through the analysis four properties are highly related to the evaluation results by the subjects, A-weighting SPL, loudness, sharpness and AI. After normalization, the four properties will then be taken as the inputs for the neural network for noise perception prediction, while the subjective rating will be the output.

Neural Network Establishment for Noise Perception Prediction

Back-propagation neural network is used [4]. Three layers including input, hidden and output formed the neural network structure. Levenberg-Marquardt algorithm proves to be with the highest rate of convergence and the lowest error after training, so the training function based on this algorithm is applied in this network [5]. According to the training and testing errors, the number of neutrons is determined as 13. Therefore, the topological structure of the neural network is 4-13-1, as shown in Figure 1.

The network can be used to determine which group of calculation method is better related to the human perception for the recorded noise through calculating the errors after training. 26 sound samples are chosen as training

Table 1: Subjective Rating Scales

Very Terrible	Terrible	Very Bad	Bad	Not Bad	Acceptable
1	2	3	4	5	6
Satisfied	Good	Very Good	Excellent	Very Excellent	
7	8	9	10	11	

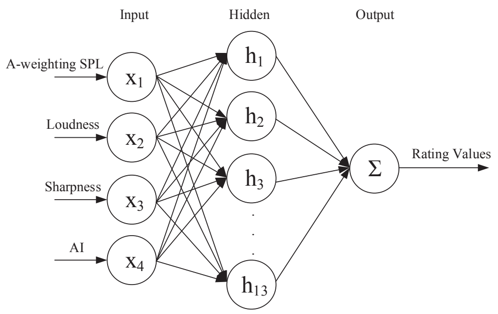

Figure 1: Structure of Neural Network for Noise Perception Prediction

samples and the rest 6 are as testing samples. Through comparison between the minimum testing mean square errors (MSEs) calculated by the 13 groups of inputs after 1000 times of training, No. 7 could be seen as having the minimum error compared with others in Figure 2.

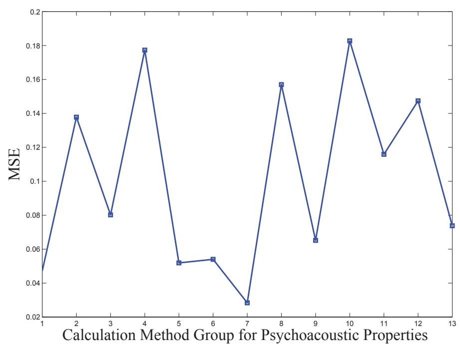

Figure 2: Minimum MSEs Comparison between 13 Groups of Inputs

In this group, Filter / ISO 532 B and von Bismarck are used to calculate loudness and sharpness. Therefore, this combination group could be regarded as the most highly related to human perception due to the smallest subjective rating prediction error. And then all the set-ups in this time of training are saved as the final network. The testing error using the network can be seen in Figure 3. None of the errors exceeding 5% proves a good prediction ability of the neural network.

Conclusions and Outlook

The neural network for noise perception prediction has been established to predict how people will feel about the sound quality of interior noise from high-speed trains. With measurements in a high-speed train, the psychoacoustic properties of the 32 sound samples are calculated

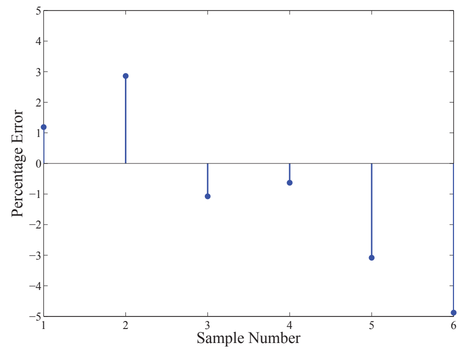

Figure 3: Prediction Percentage Error

by different calculation methods, and subjects are invited to evaluate on the sound samples. Through simulating in the established network, it is concluded that when Filter / ISO 532 B and von Bismarck are as the calculation methods for loudness and sharpness, the prediction results are closest the real testing results.

For the future work, more subjects and more measurements are necessary to validate the network. Besides, how human perception change with the change of properties and which kind of interior noise is acceptable for the passengers.

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