Buenos Aires – 5 to 9 September, 2016
Acoustics for the 21st Century…

PROCEEDINGS of the 22nd International Congress on Acoustics

Product Sound Quality and Multimodal Interaction: Paper ICA2016-557

A sound quality model for washing machine sounds based on artificial neural network

Altinsoy, M. Ercan [a], Atamer, Serkan [a]

[a] Chair of Acoustic and Haptic Engineering, Technische Universitaet Dresden, Germany.
ercan.altinsoy@tu-dresden.de

Abstract

The sounds of the washing machines are one of the most complicated household product sounds. They are instationary and contains different operating stages which cause totally different sounds. These aspects make the psychophysical evaluation and the modelling of the overall washing machine sound quality very difficult. Washing and spin are two main operational stages. Particularly spin sounds are loud and highly instationary with various sound events. The aim of this study to predict the sound quality perception of front-loading washing machines using artificial neural networks. Therefore a listening test was conducted, in which the participants evaluated the pleasantness/annoyance of the washing machine sounds. Then the psychoacoustical and signal features of the sounds were analysed. The link between the listening test results and analysis results were realized using artificial neural networks (ANNs). Finally the model which is based on the ANNs was verified using test stimuli. The results of the study was compared with the models from our previous studies.

Keywords: Household appliance, sound label, quality, design, neural networks.

A Sound Quality Model for Washing Machine Sounds Based on Artificial Neural Network

1 Introduction

In recent years, various research studies were conducted taking into account the increasing importance of the sound quality of household appliances [1, 2, 3, 4, 5, 6, 7]. Particularly the annoying household appliance sounds cause the degradation of the life quality. Therefore a knowledge on the signal properties and psychoacoustical parameters which are important for the perceived annoyance is very helpful for the manufacturers. Studies on the household appliances show that loudness, sharpness, roughness and tonality are very useful to describe the perceived annoyance [3, 5]. Most of the existing sound quality indexes for household appliances are based on the regression model which considers the multiple linear regression between the subjective evaluation results and the psychoacoustical properties [1…7]. Well known methodology from the machine learning and cognitive science, artificial neural networks (ANNs) opens up new opportunities for the sound labelling. Main advantage of the artificial neural networks in comparison to traditional regression based sound indexes is that ANNs have the capability of learning and pattern recognition. Therefore some researchers applied the ANN to estimate the sound quality judgments and model the sound quality evaluation process in recent years [8, 9, 10, 11, 12, 13, 14]. Most of these investigations concentrated on the application of the ANN on the vehicle sound quality prediction [8, 9, 10, 13, 14]. Simulation results deliver in most cases very well correlation with the subjective judgments.

The aim of this study is to develop a sound quality model which is based on artificial neural network for washing machine sounds. In our recent study [15] we conducted perceptual evaluation tests for washing machine sounds and analysed the psychoacoustical parameters. Using the knowledge and results from our previous study, we developed an ANN model for washing machine sounds. First we will summarise the content of our recent study and then we will introduce the developed ANN model.

2 Listening Test – Annoyance Evaluation of Washing Machine Sounds

The conducted listening test and the annoyance evaluation results were reported in [15]. 9 front loaded washing machines were recorded for the investigation. The maximum rotation speed of the machines was 1200 rpm. Characteristic time sequences from various operating conditions were selected as stimuli for the listening test. The selected stimuli contains water, pump, friction and spin noises. Average duration of the stimuli was 5 sec. Additionally, the original recorded sounds (selected stimuli) were modified in frequency and time domain using various digital filters.

Twenty subjects participated in the listening experiments. The ages of eight men and twelve women participants varied between twenty-two and sixty-one years. All participants were naïve without any acoustical knowledge. They evaluated the annoyance of the stimuli on a quasi-continuous scale using a slider. This scale consists of verbal markers not at all, slightly, moderately, very, and extremely. The length of the slider was 100 mm with a resolution of 1 mm (100: extremely annoying, 0: not annoying). The listening test contained a training. In this training session, different stimuli combinations from the experiment was presented to the participants to give information about the stimuli variance.

The results of the listening experiment showed that the perceptual annoyance ratings of the washing machine sounds vary strongly. There is a significant difference between the water sounds which cause much more less annoyance and spinning sounds. It was also observed that the pump noises should be taken into account regarding the perceived annoyance.

The results of the conducted evaluation experiment and signal/psychoacoustical analysis show that loudness, sharpness, roughness and tonality are most important psychoacoustical parameters in regard to the perceived annoyance of the washing machine sounds. Particularly the spin cycle is very loud and annoying, loudness is very important parameter for the perception of the washing machine sounds. Sharpness takes into account the perceived annoyance of the high frequency components, which are very dominant in some spin sequences, of the washing machine sounds. The roughness and the tonality provide a good overview on the resulted annoyance of the modulated and tonal sound components.

3 Development of an Annoyance Estimation Model Based on Artificial Neural Network

The artificial neural network, which was developed in this study, is a two-layer feed-forward neural network.

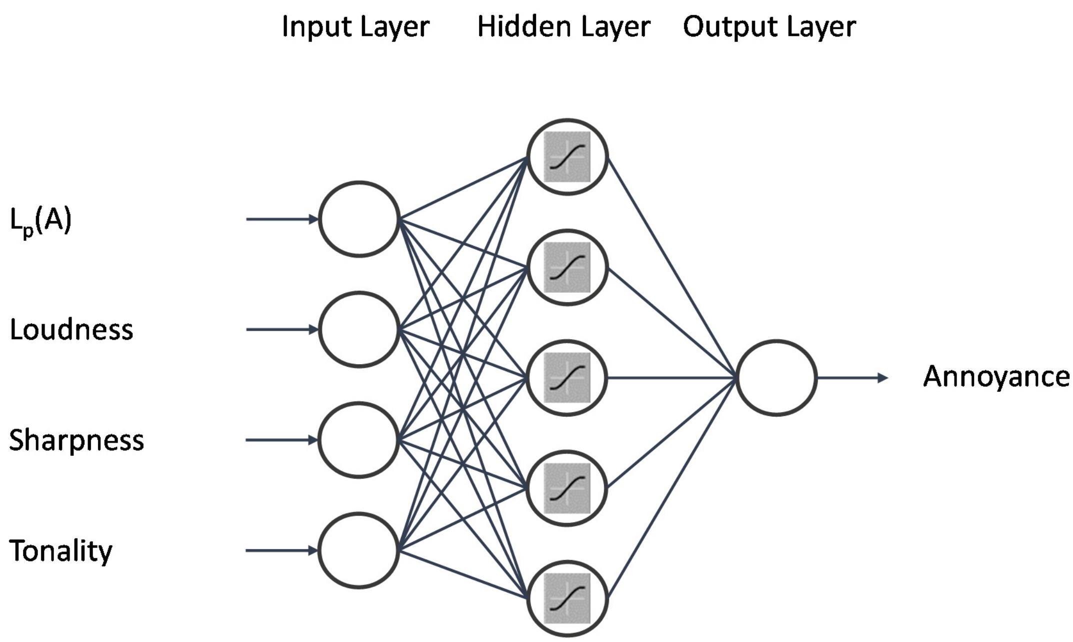

Figure 1: Structure of the developed ANN

As activation functions in hidden layers, sigmoid functions were applied. The number of hidden neurons was 5. As training algorithm, the Bayesian Regularization method was used. The performance estimation is based on the Mean Squared Error. Above mentioned four psychoacoustical properties, loudness, sharpness, roughness and tonality, were used as inputs (Figure 1).

Annoyance ratings of the 26 stimuli is presented in a box plot in Figure 2. Median values are shown in red and mean values are the mid points of the represented boxes. Edge of the boxes are the 25th and 75th percentiles of the population, and extreme data points (outliers) are plotted individually as red plus signs.

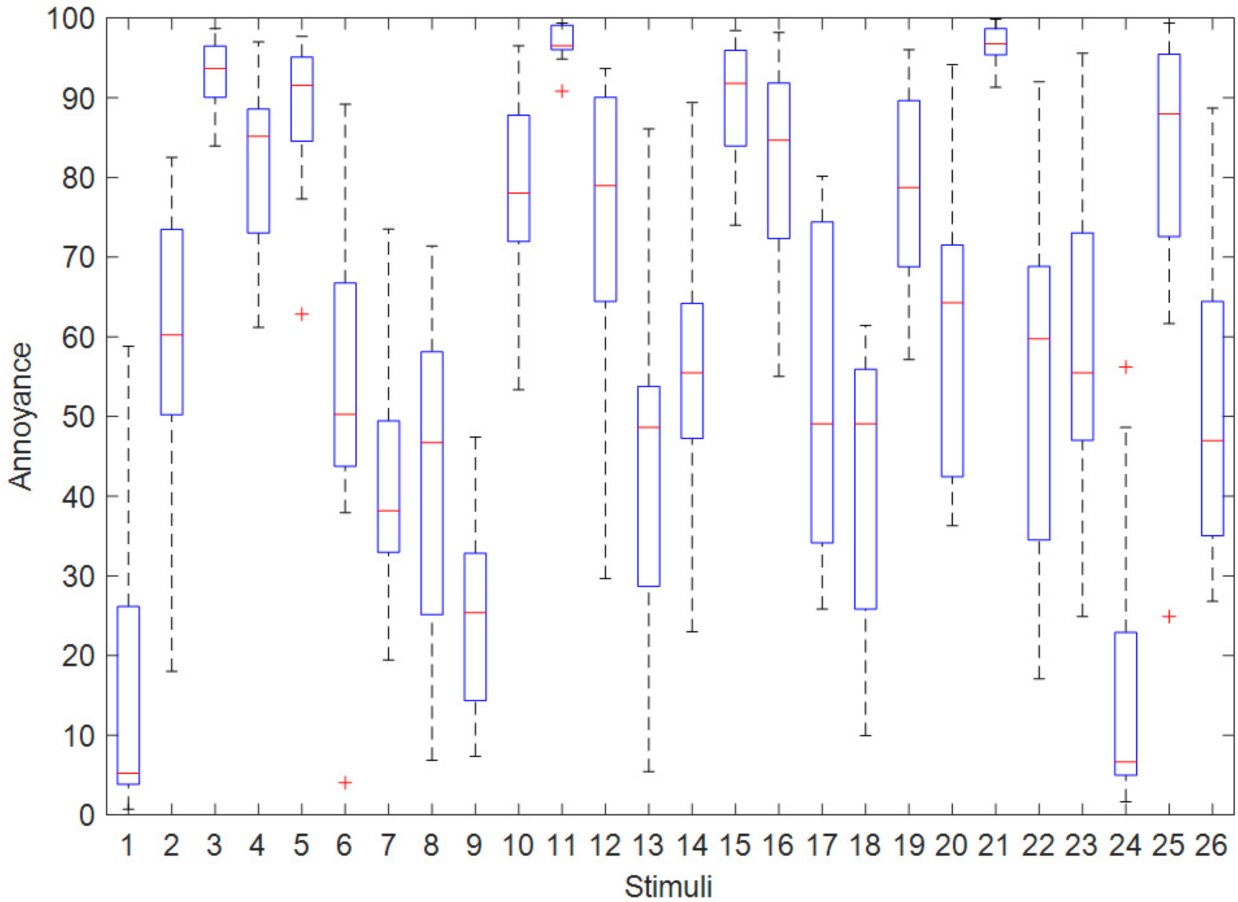

Figure 2: Annoyance ratings of the washing machine sounds

Neural networks should be trained with as many different data sets possible. That would increase the flexibility of a neural network to estimate data points lying outside of the main trend of the overall data set. In this example, two neural network training algorithm is obtained. In the first example, neural network is trained by 17 data set among 26. Remaining parts are used as the validation for the stimuli. Selection of the 17 data set is randomized, such that at each training, different data sets are selected to obtain best neural network performance in terms of mean squared errors and regression values. The tailored neural network is then used for estimating the whole data sets available and comparison with the subjective estimations are presented. In the second phase, data points lying out of the main trend in terms of the annoyance estimations, which can be called as “extreme values” (in this case 3., 5., 11., 15., 21. and 25. stimuli) , are excluded from training set, and remaining 20 stimuli value are used for training the neural network. In this trial, the main aim is to understand, if the neural network is capable of mimicking “out of bounds” estimations rather than normal, usual, linear trend data set. In other words, neural network is trained only with *normal* data sets and expected to imitate even *anormal* values to some degree. It should be noted that, the criteria for the exclusion of the extreme stimuli was the annoyance ratings in this study. However, different divisions can also be possible in terms of the input values, i.e. calculated psychoacoustical values of the stimuli such as sharpness and tonality.

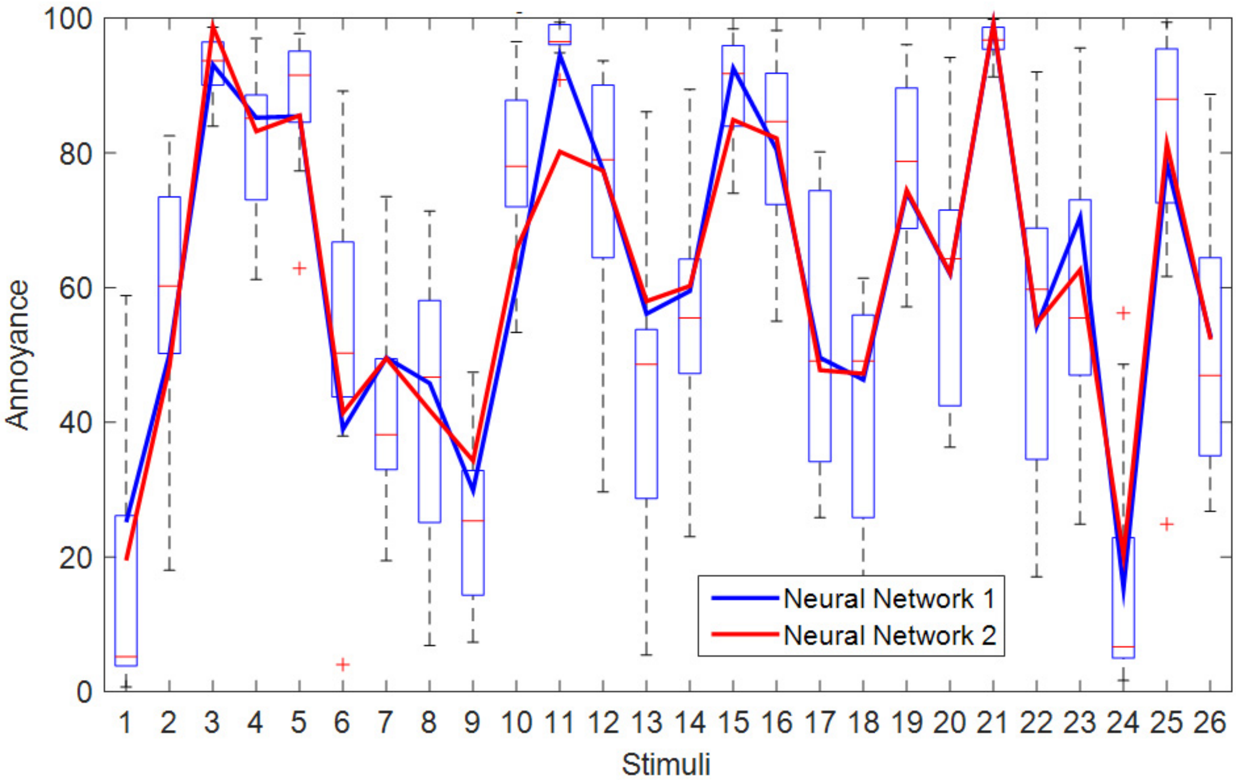

Figure 3: Results obtained from ANN compared to subjective annoyance ratings

The performance of the first neural network was slightly better than second neural network. Particularly, second neural network cannot deliver good results for the stimuli 11. or 15.

4 Conclusions

In this study, a 4-input 1-output artificial neural network system was developed to model the perceived annoyance of the washing machine sounds. The ANN is based on the perceptual evaluation experiment results. Psychoacoustical properties, which are loudness, sharpness, roughness and tonality are the inputs of the ANN. The results of the ANNs show high correlations with the subjective ratings. Two different training algorithm, such as *random selected data set* and *extreme value out*, were applied to develop the ANN. The results show that the random selected data strategy deliver better results.

References

[1] Altinsoy, M. E.; Gül, M.; Kuyumcuoglu, A. Sound Quality of Household Appliances for Life Quality–An Investigation on Tumble Dryer Sound Quality. *Proceedings of 22nd ICSV*, Florence, 2015. In CD-ROM.

[2] Sato, S.; You, J.; Jeon, J. Y. Sound quality characteristics of refrigerator noise in real living environments with relation to psychoacoustical and autocorrelation function parameters. *J Acoust Soc Am.* Volume 122 (1), 2007, pp. 314-25.

[3] Bowen, D. L. Sound Quality Studies of Front-Loading Washing Machines. *Sound and Vibration,* 2010.

[4] Jeong, U. et al. Development of a sound quality index for the wash cycle process of front-loading washing machines considering the impacts of individual noise sources. *Applied Acoustics* Volume 87, 2015, pp. 183–189.

[5] Altinsoy, M.E. The Sounds of Household Appliances and its Relationship with the Quality of Life in *Proceeding of the Internoise 2015*, San Francisco, USA, 2015. In CD-ROM.

[6] Altinsoy, M. E.; G., Kanca; H. T. Belek A Comparative on the Study Sound Quality of Wet-And-Dry Type Vacuum Cleaners in *Proc. of Sixth ICSV*, Lyngby, Denmark, 1999, pp. 3079-3086.

[7] Atamer, S.; Altinsoy, M. E. Estimation of Electric Shaver Sound Quality Using Artificial Neural Networks. *Proceedings of Internoise 2016*, Hamburg 2016. In CD-ROM.

[8] Lee, S.; Byung-Soo, K.; Dong-Chul, P. Objective evaluation of the rumbling sound in passenger cars based on an artificial neural network”. *Proceedings of the Institution of Mechanical Engineers*, Part D: Journal of Automobile Engineering, volume 219.4, 2005, pp.457-469.

[9] Lee, S.; Tae-Gue, K; Usik, L. Sound quality evaluation based on artificial neural network." Advances in Natural Computation. Springer Berlin Heidelberg, 2006, pp. 545-554.

[10] Wang, Y. S., et al. Sound-quality prediction for nonstationary vehicle interior noise based on wavelet pre-processing neural network model. *Journal of Sound and Vibration* Volume 299 (4), 2007, pp. 933-947.

[11] Pietila, G.; Teik, C. L. Intelligent systems approaches to product sound quality evaluations–A review. *Applied Acoustics* Vol. 73(10), 2012, pp. 987-1002.

[12] Pellegrini, C.; Edmar, B. Sound Quality Evaluation of Hermetic Compressors Using Artificial Neural Networks. *Proceedings of the International Compressor Engineering Conference*, 2006.

[13] Yıldırım, Ş.; Eski, I. Sound quality analysis of cars using hybrid neural networks. Simulation Modelling Practice and Theory Volume 16(4), 2008, pp. 410-418.

[14] Lee, H.; Sung-Jong, K; Sang-Kwon, L. Design of new sound metric and its application for quantification of an axle gear whine sound by utilizing artificial neural network. *Journal of mechanical science and technology* Volume 23(4), 2009, pp. 1182-1193.

[15] Altinsoy, M. E.; Gül, M.; Kuyumcuoglu, A. Washing Machine Sound Quality. *Proceedings of 23rd ICSV*, Athen, 2016. In CD-ROM.