International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:9, No:8, 2015

Neural Networks-Based Acoustic Annoyance Model for Laptop Hard Disk Drive

Yi Chao Ma, Cheng Siong Chin, Wai Lok Woo

***Abstract*—**Since the last decade, there has been a rapid growth in digital multimedia, such as high-resolution media files and three-dimentional movies. Hence, there is a need for large digital storage such as Hard Disk Drive (HDD). As such, users expect to have a quieter HDD in their laptop. In this paper, a jury test has been conducted on a group of 34 people where 17 of them are students who are the potential consumer, and the remaining are engineers who know the HDD. A total 13 HDD sound samples have been selected from over hundred HDD noise recordings. These samples are selected based on an agreed subjective feeling. The samples are played to the participants using head acoustic playback system, which enabled them to experience as similar as possible the same environment as have been recorded. Analysis has been conducted and the obtained results have indicated different group has different perception over the noises. Two neural network-based acoustic annoyance models are established based on back propagation neural network. Four psychoacoustic metrics, loudness, sharpness, roughness and fluctuation strength, are used as the input of the model, and the subjective evaluation results are taken as the output. The developed models are reasonably accurate in simulating both training and test samples.

***Keywords*—**Hard disk drive noise, jury test, neural network model, psychoacoustic annoyance.

I. Introduction

A. Sound in Hard Disk Drive (HDD) Design

JUST like color, shape, and function, sound is an important feature that potential users consider when purchasing a product, especially one that has a moving part. In the past, product designers are more concerned with the loudness of the sound generated from their products. Nowadays, however, diversified user expectation requires product designers to understand more about human perception of sound, and to address both sound loudness and pleasantness [1]. A hard disk drive (HDD) is a key component in a laptop system and generates unwanted sound (also known as noise) when it in operation mode. In the early days, HDD users cared a lot more about the capacity of a HDD than its noise level. Many users were not even aware that a HDD generates mechanical noise when it is working, because this noise was often masked by sounds made by other components such as the CPU fan, the secondary fans and the CD/DVD player. As technology has advanced, many of these components have been either removed or designed to operate only when needed. For example, the CPU fan only starts to rotate when the CPU is too hot to function normally. As a result, the HDD noise becomes more significant in the overall laptop user experience.

YiChao Ma is with mechanical department of Seagate Singapore Design Center. The Shugart Building, SSDC, 26 Ayer Rajah Crescent, Singapore 139944 (phone: 65-6807-7595; e-mail: yichao.ma@seagate.com).
ChengSiong Chin is with School of Marine Science & Technology (MaST) Newcastle University International Singapore 537 Clementi Road #06-01 (Rm: 06-43), Singapore 599493 (e-mail: cheng.chin@ncl.ac.uk).
Wak Lok Woo is with School of Electrical and Electronic Engineering, Newcastle University, NE1 7RU, England, United Kingdom (e-mail: lok.woo@ncl.ac.uk).

B. Source of Noise in HDD

According to ISO 7779:2001 [2], a HDD operates in two modes, i.e. the idle mode and the operating mode. Noise is generated in both modes in different patterns. In the idle mode, no data reading or writing takes place. The disk is simply driven by the spindle motor to rotate at a constant and high speed. Here noise is mainly contributed by the mechanical noise from the spindle motor, and is worsened by the wind age noise caused from friction between the rotating disk and air. In the operating mode, on the other hand, data are read from or written into the HDD. During this process, the actuator arm moves the magnetic head violently across the disk, introducing additional noises as compared to that in the idle mode. This arm motion is driven by the voice coil motor (VCM) in the HDD. Different from spindle motor which rotates at a constant speed, the rotation speed of the VCM largely depends on the situation and the noise generated is different. Hence, the noise generating in the operating mode is more complicated than that in the idle mode.

Fig. 1 A typical 2.5” Hard Disk Drive

C. Health Effects of Noise

WHO defines health, as “health is a state of complete physical, mental and social well-being, and not merely the absence of disease or infirmity” [3]. Noise could be a health hazard to our daily life. When a noise is too loud, it could physically damage the hearing organs either permanently or temperately. However, even when a noise is not loud, it could still disturb our daily activities such as sleep and work, and causes various mental problem [4]. After years of manufacturing effort, nowadays the noise level of a 2.5” HDD is normally below 30 dB. At this level, the HDD noise will not cause hearing loss but might disturb the end user's daily life or cause noise annoyance [5].

In Oxford Dictionary, annoyance is defined as the feeling or state of being annoyed or irritation. Noise annoyance is the annoyance caused by noise and can lead to stress and sleep disturbance, and in some instances even influence the nerve system [6].

How pleasant or annoying humans find a sound to be is studied in psychoacoustics. In their book, E. Zwicker and H. Fastl [7] defined psychoacoustics as a quantitative correlation between acoustic stimuli and the hearing sensations. Psychoacoustic parameters include loudness (L), sharpness (S), fluctuation strength (FS) and roughness (R). All these parameters can be used to characterize human feeling about noise annoyance.

In this study, an in-depth study will be conducted to investigate the HDD noise annoyance and develop a neural networked model to predict this feeling using objective psychoacoustic parameters.

II. Subjective Assessment of HDD Noise

A. Overall Approach

Fig. 2 represents the over concept of this study. HDD noises have been recorded in the anechoic chamber using the binaural head. Then they would play to the participants through PEQ V and Bose low noise headphone. The participants are required to base on their own judgment to judge whether the sound they perceived are annoyed or not. Meanwhile the noises also process through software to obtain their corresponding loudness, sharpness, roughness and fluctuation strength values. With four psychoacoustic parameters as the input and the subjective rating from human participants as output, a neural network based model for HDD is derived.

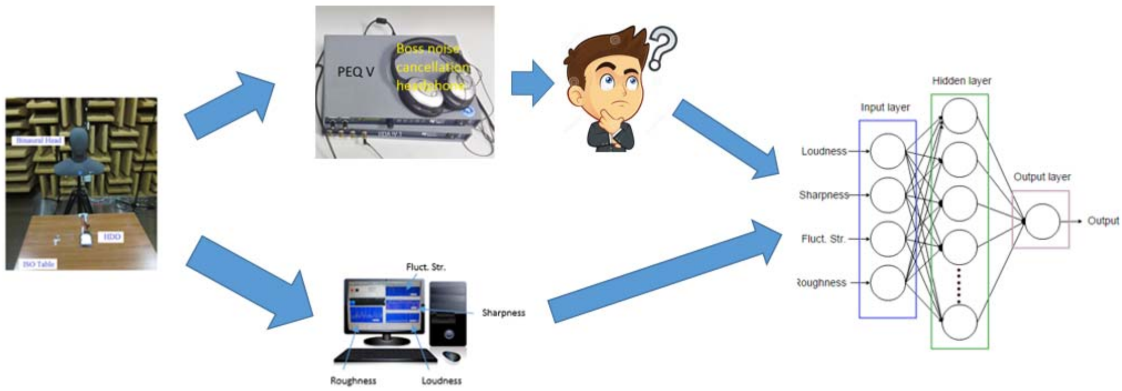

Fig. 2 Overall concept of Annoyance study

B. Test Preparation

R. H. Lyon [1], [8] proposed that listening test (also called jury test) could be used as a tool to study how human feels about the sound of a product. He also suggested a general guideline for the jury panel test consisting of four steps:

1) The first step is to select the jury members. The jury members can either be the engineers who know the product, or potential customers who might use the product. However, if the engineers are to be chosen as the jury members, their answers might be biased due to their knowledge about the product. If the potential customers are to be selected, then the identification of those customers becomes critical. In this study, a total 34 persons consist of 17 of age 18 to 26 Newcastle students and 17 of age from 28 to 55 engineers are invited to participant in this jury test
2) A meaningful scaling system is required for the jury test. The jury members are to be asked to scale their feelings about the sound they hear. Generally, it can be a fixed scale, e.g. 1 to 10, or a comparison scale, e.g. compared to A, sound B is softer. In this study, a comparison scale is used.
3) The stimulus set is a group of sound samples that the jury members are going to hear. Normally, they can be selected from a large group of sound recordings. The most representative sounds of the product should be chosen. A total thirteen noise samples which having sound pressure level of less than 30 dB(A) are short listed from a hundred HDD noise recordings. Fig. 3 shows their sound pressure readings.
4) The last step is to conduct the listening test. Using headphones is the most convenient way, hence a binaural recording is needed.

C. Jury Test

The jury test was conducted in a big lecture theater as shown in Fig. 4. Four participants sat in the center of the room and they listen to the noise samples each time. All the participants have been instructed to listen to the noise samples, compared between current to previous noise, and made a comparison judgment. Five level scales of very annoyed, annoyed, same, ok and better were used in the jury test.

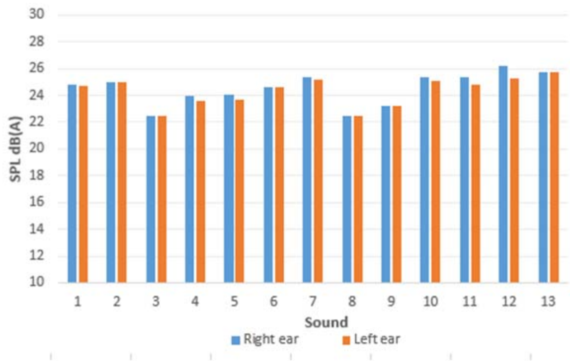

Fig. 3 Sound pressure level for the thirteen-noise sample

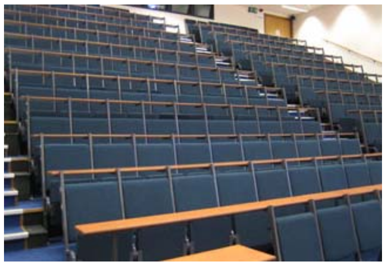

Fig. 4 Room conducted the jury test

D.Subjective Performance and Psychoacoustic Analysis

Fig. 5 and 6 represent the results of the subjective study (i.e. jury test). A clear difference can be observed from these two groups of participants. It is very differences to the sound pressure level (Fig. 2). Hence, psychoacoustic analysis has been computed.

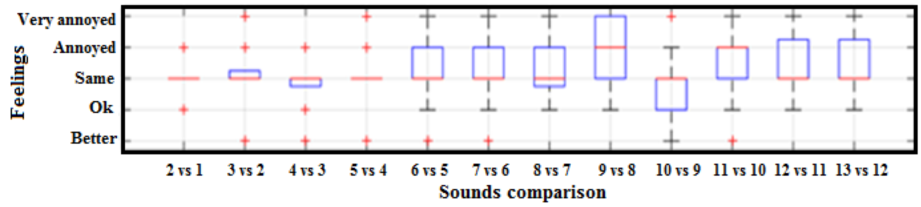

Fig. 5 Newcastle student results of the jury test

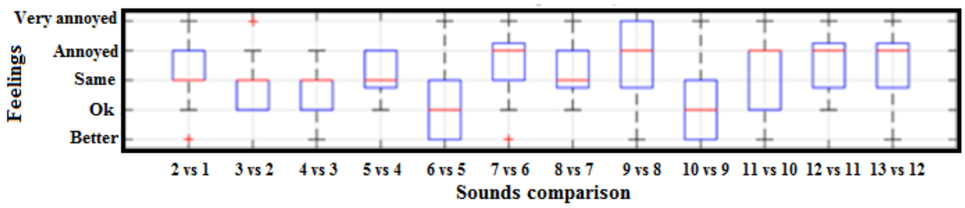

Fig. 6 Engineers results of the jury test

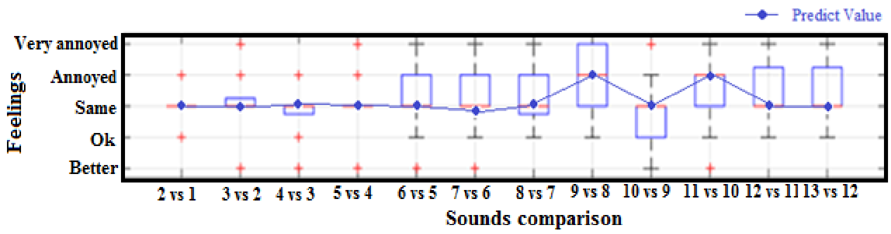

Fig. 8 Students predicted value vs. jury test results

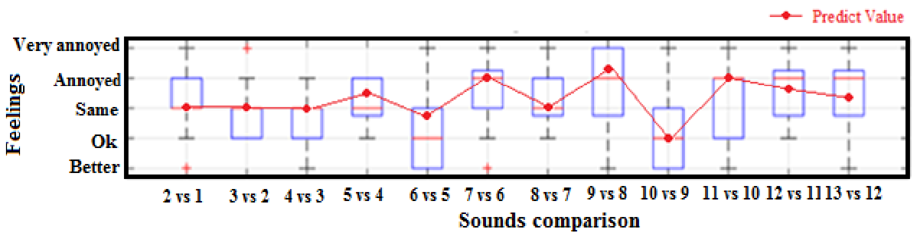

Fig. 9 Engineers predicted value vs. jury test results

International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:9, No:8, 2015

TABLE I
PSYCHOACOUSTIC RESULTS FOR EACH NOISE SAMPLE

Noise Sample	Loudness (Sone)	Sharpness (Acum)	Flu. Str. (Vacil)	Roughness (Asper)
1	0.45	2.21	0.0059	0.0103
2	0.40	2.15	0.0051	0.0093
3	0.25	2.20	0.0047	0.0079
4	0.35	1.85	0.0059	0.0104
5	0.36	1.86	0.0059	0.0106
6	0.36	1.78	0.0049	0.0093
7	0.41	2.09	0.0073	0.0177
8	0.25	2.38	0.0023	0.0095
9	0.29	2.21	0.0029	0.0130
10	0.34	1.80	0.0043	0.0103
11	0.50	1.80	0.0051	0.0145
12	0.57	1.80	0.0063	0.0173
13	0.53	1.81	0.0051	0.0167

TABLE II
RATE OF CHANGE (%) FOR EACH SOUND COMPARISON

Sound Comparison	Rate of change (%)			
	Loudness	Sharpness	Flu. Str.	Roughness
2 vs 1	-11.1%	-2.7%	-13.6%	-9.7%
3 vs 2	-37.5%	2.3%	-7.8%	-15.1%
4 vs 3	40.0%	-15.9%	25.5%	31.6%
5 vs 4	2.9%	0.5%	0.0%	1.9%
6 vs 5	0.0%	-4.3%	-16.9%	-12.3%
7 vs 6	13.9%	17.4%	49.0%	90.3%
8 vs 7	-39.0%	13.9%	-68.5%	-46.3%
9 vs 8	16.0%	-7.1%	26.1%	36.8%
10 vs 9	17.2%	-18.6%	48.3%	-20.8%
11 vs 10	47.1%	0.0%	18.6%	40.8%
12 vs 11	14.0%	0.0%	23.5%	19.3%
13 vs 12	-7.0%	0.6%	-19.0%	-3.5%

III. NEURAL NETWORK MODELING

Artificial Neural Network (ANN) is a software or hardware model inspired by structure and behaviors of biological neurons and neuron systems [9]-[11]. There are many types of neural networks but in this study, the back-propagation neural network is used (Fig. 7). It is the most often model used to solve the nonlinear regression tasks by learning from audio data. Other competing models beside the ANN include the matrix factorization [12]-[13].

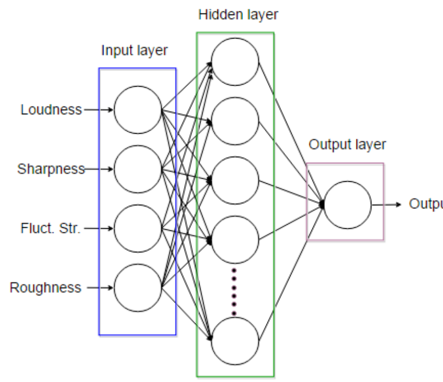

Fig. 7 General architecture for ANN used

MATLAB™ neural network toolbox is used to develop the model. A two-layer network with sigmoid hidden neurons and linear output neurons is selected. The network trained with different backpropagation algorithm with different number of neurons in the hidden layer to find out the best number of neurons and backpropagation algorithm. Mean absolute relative error (MARE) and root mean square error (RMSE) are used as the criteria for the predication accuracy of the model.

$$MARE = \left(\sum_{i=1}^{n}\left|\frac{y_i - t_i}{t_i}\right|\right)\% \quad (5)$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - t_i)^2} \quad (6)$$

where n=12, y is the predicted value by the model and t is the actual jury result.

In this study 85% of the data set was used randomly to train the network and 15% to test. Three types of training algorithm and 6 to 12 hidden neurons are evaluated. Table III and IV showed the results for student group and engineers group respectively.

TABLE III
PERFORMANCE OF EACH TRAINING ALGORITHM FOR STUDENTS

Training Algorithm	Hidden Neurons	MARE	RMSE	R
Levenberg-Marquardt	12	7.48%	0.16	0.91
Bayesian Regularization	12	83.00%	0.36	0.43
Scaled Conjugate Gradient	12	15.44%	0.15	0.92
Levenberg-Marquardt	**10**	**2.72%**	**0.07**	**0.99**
Bayesian Regularization	10	70.45%	0.37	0.46
Scaled Conjugate Gradient	10	0.48%	0.13	0.95
Levenberg-Marquardt	8	8.43%	0.18	0.89
Bayesian Regularization	8	57.56%	0.33	0.55
Scaled Conjugate Gradient	8	0.49%	0.12	0.96
Levenberg-Marquardt	6	29.94%	0.20	0.84
Bayesian Regularization	6	0.00%	0.36	0.70
Scaled Conjugate Gradient	6	0.12%	0.13	0.95

TABLE IV
PERFORMANCE OF EACH TRAINING ALGORITHM FOR ENGINEERS

Training Algorithm	Hidden Neurons	MARE	RMSE	R
Levenberg-Marquardt	12	29.19%	0.35	0.91
Bayesian Regularization	12	36.34%	0.45	0.82
Scaled Conjugate Gradient	12	2.68%	0.40	0.90
Levenberg-Marquardt	10	3.17%	0.40	0.88
Bayesian Regularization	10	31.05%	0.38	0.86
Scaled Conjugate Gradient	10	27.51%	0.38	0.85
Levenberg-Marquardt	**8**	**17.00%**	**0.27**	**0.94**
Bayesian Regularization	8	34.42%	0.39	0.85
Scaled Conjugate Gradient	8	12.96%	0.32	0.90
Levenberg-Marquardt	6	8.21%	0.31	0.91
Bayesian Regularization	6	33.23%	0.41	0.86
Scaled Conjugate Gradient	6	4.67%	0.43	0.85

As a result, the models for each age group have been identified and highlighted in Table III and IV. As shown in Figs. 8 and 9, the developed neural network based models are able to predict the annoyed feeling by laptop hard disk drive with minimum error.

IV. Conclusion

Noise annoyance predication is very important topic for the HDD noise control. The proposed back-propagation neural network models are able to predict the annoyed feeling by laptop hard disk drive with minimum error. Two distinct groups' participants such as students and engineers were examined. This method provides a tool for subsequent design and control the noise level from HDD. Future works are needed to verify the usefulness of the model and further optimization of the mode using other methods.

Acknowledgment

The author would like to thank the Seagate Singapore Design Center (SSDC) and EDB-IPP scholarship on Psychoacoustics study of HDD for the test facilities, technical advice and scholarship.

References

[1] R. H. Lyon, "Designing for Product Sound Quality", Marcel Dekker, Inc. 2000.
[2] "Acoustic Measurement of Airborne Noise Emitted by Information Technology and Telecommunications Equipment", BS EN ISO 7779:2001
[3] World Health Organization 1960 Constitution, Geneva: World Health Organization.
[4] Y. Osada, "An Overview of Health Effects of Noise", J. Sound Vib. 127(3), 407-410. 1988.
[5] S. Choi, W. Moon, S. Gang, T. Hwang, "Human-Based Evaluation of Sound from Hard Disk Drives for Noise Control", Microsyst. Technol. 10, 640-648 © Springer-Verlag 2004.
[6] Goshen, C E, "Noise, Annoyance, and Progress", Science (New York, N. Y.), Vol. 144(3618), pp. 487, 1964.
[7] H. Fastl, E. Zwicker, "Psycho-Acoustics Facts and Models" 3rd edition, Springer (2007).
[8] R. H. Lyon, "Engineered Sound Quality Coupling Subjective Reactions to Engineering Choices", (IEEE) Ind. Appl. Mag. Vol 6, Nov/Dec 2000.
[9] V. Kecman, "Learning and Soft Computing", the MIT press (2001).
[10] W.L. Woo and S.S. Dlay, "Neural network approach to blind signal separation of mono-nonlinearly mixed signals", (IEEE) Circuits and System I, 52(2), 1236-1247, 2005.
[11] W.L. Woo and S.S. Dlay, "Nonlinear Blind Source Separation Using a Hybrid RBF-FMLP Network", (IEE) Vision, Image and Signal Processing, 152(2), 173-183, 2005.
[12] Bin Gao, W.L. Woo and L.C. Khor, "Cochleagram-Based Audio Pattern Separation Using Two-Dimensional Non-Negative Matrix Factorization with Automatic Sparsity Adaptation," J. Acoust. Soc. Am., 135(3), 1171-1185, 2014.
[13] Bin Gao, W.L. Woo and S.S. Dlay, "Unsupervised Single Channel Separation of Non-Stationary Signals Using Gammatone Filterbank and Itakura-Saito Nonnegative Matrix Two-Dimensional Factorizations," (IEEE) Circuits and Systems I, 60(3), 662-675, 2013.