Applied Acoustics 140 (2018) 178–182

Contents lists available at ScienceDirect

Applied Acoustics

journal homepage: www.elsevier.com/locate/apacoust

Development of psychoacoustic model based on the correlation of the subjective and objective sound quality assessment of automatic washing machines

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ARTICLE INFO

Keywords:
Psychoacoustics
Washing machines
Multi-criteria method
Sound quality evaluation

ABSTRACT

In practice, the procedures of the sound quality assessment are often different and do not guarantee the same results in ranking the products from best sound quality to worst. The main objective of this paper is to develop the sound quality index that will ensure the objective assessment of the sound quality of automatic washing machines. The sound quality index is based on the determination of weighting factors for five selected psychoacoustic quantities. The weighting factors have been obtained by the correlation and subsequent statistical processing of the objective binaural measurement and the questionnaire survey with 81 respondents. Point scores obtained from the respondents were subsequently statistically correlated with measured psychoacoustic parameters by the multi-criteria method, namely the weighted sum method (Pearson). By the application of the obtained weighting factors to the measured psychoacoustic parameters, it is possible to objectively determine the sound quality index of automatic washing machines without the questionnaire survey.

1. Introduction

At the ICSV13 congress in Vienna 2006, Fastl [1] stated that psychoacoustics is the scientific sphere to bridge the gap between physical and subjective assessments, since the solid links are determined between the physical representations of sounds and the correlation sense of hearing during psychoacoustical experiments. According to Zwicker and Fastl [2], the most used psychoacoustic parameters for the sound quality assessment include loudness, sharpness, roughness and fluctuation strength. The combination of these fundamental psychoacoustical quantities may, in many experiments, predict the sound quality assessment by the subjects. Many psychophysical methods described, for example, by Hellbrück and Ellermeier [3] or Fastl [4], are used to assess the sound quality in the psychoacoustics and sound engineering.

The quality of household appliances sound is currently a very interesting subject not only from the point of view of an end user, as well as manufacturers, who are interested in the sound quality of their products as a part of marketing and competitiveness. Some trends in the applied acoustics, psychoacoustics and the practical applications are described in the articles [5–7]. Over the past 20 years, there has been a growing demand from the user industry as well as from the customers themselves for products not only in terms of sound quantity but better sound quality. A large part of the research is focused on the automotive industry and related products. It can be seen in many publications and studies dealing with, for example, the psychoacoustic assessment of the sound of an outside rearview mirror [8], by sound of five different automobiles [9], through the psychoacoustical analysis of gearbox faults [10], the training program for automotive engineers involved in a perception assessment of automobile sound quality [11], the creation of the psychoacoustic model for a combustion engine sound quality assessment [12], the comparison of rattle noise of car steering wheel through psychoacoustic parameters and subjective assessment [13], the sound quality assessment of synchronous engines in electrical cars [14], as well as the proposal of a psychoacoustic model in the development of exhaust systems [15].

Another sphere, where the psychoacoustics is currently utilized is the assessment of household appliance sound quality. The authors have analysed and assessed 24 refrigerators in [16], where they employed the parameters of psychoacoustic and autocorrelation function (ACF) to describe the temporal fluctuations of refrigerator noise. To determine the relation between the objective measures and subjective evaluation, they applied a multiple regression analysis. In the end, they developed the sound quality indices based on the psychoacoustic and ACF parameters. Subsequently, the sound quality index predicting the subjective

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https://doi.org/10.1016/j.apacoust.2018.05.025
Received 27 February 2018; Received in revised form 24 May 2018; Accepted 29 May 2018

score was proposed in [17]. It is the result of the correlation and multiple regression analysis of the psychoacoustic parameters and subjective assessments of 30 types of refrigerators. Kuwano et al. [18] published the results of other experiments focused on the assessment of household appliance sound quality, e.g. washing machines, microwave ovens, vacuum cleaners and dishwashers and Takada et al. [19] published the evaluation results of the economic value of the sound quality of hairdryers and vacuum cleaners.

Not least, the interests in the sphere of assessing product sound quality are reflected in the IT sphere. An extensive psychoacoustic case study with over 200 participants in four countries was carried out to determine the quality of sound from information technology products and its results can be found in Beltman et al. [20]. The documents [21,22] include the indices of a printer sound quality developed by various approaches through which it is possible to assess the sound quality of selected printers objectively and subjectively.

The objective of this paper is to create a psychoacoustic model developed on the basis of the correlation of the objective and subjective assessment of sounds of 5 automated washing machines produced by five different manufacturers using a multi-criteria method, namely the weighted sum method. This psychoacoustic model is the function of five fundamental psychoacoustic parameters and is developed to assess washing-machine sound quality on the basis of objective assessment of psychoacoustic metrics only without the subjective evaluation from respondents.

2. Material and methods

2.1. Measurement description

For the above mentioned research purposes, five models of front-loaded automatic washing machines of the highest product class made by different manufacturers were selected. Two methods were used for the sound quality assessment of automatic washing machine by measuring sound quality using the binaural measuring device and by questionnaire survey. Three operation modes of the automatic washing machine (fill, wash, spin) were assessed by both methods.

2.2. Recording of washing machine sounds and their assessment

Recording of automatic washing machine sound was carried out in a semi-anechoic chamber. The sound of automatic washing machines was recorded by the binaural measuring device from Head Acoustic as shown on Fig. 1. The binaural head with built-in microphones was placed within 1 m from the automatic washing machine and 1.5 m above the floor level. The whole washing cycle for individual washing machines was recorded. Subsequently, three operation modes were selected for the assessment: Filling with water, washing, and spinning. The binaural signals were subsequently used for working out the assessment of sound quality for these three modes.

Fig. 1. Recording of washing machine sounds in semi-anechoic chamber.

Table 1
Psychoacoustic metrics used in objective analysis.

Metrics	Units
Loudness	Sone
Sharpness	Acum
Roughness	Asper
Fluctuation Strength	Vacil
Tonality	Ratio

2.3. Determination of sound metrics

The sound metrics are employed in the determination of sound objective characteristics. According to psychoacoustics theory, four basic psychoacoustic metrics are defined: sharpness, roughness, loudness and fluctuation strength (Table 1) [2]. In addition to these basic psychoacoustic metrics, many other ones, applicable to various spheres, have been developed. For the research and assessing the sound quality of automatic washing machines, these four above mentioned parameters, plus the fifth parameter – tonality, were selected. These five psychoacoustic parameters were calculated by Artemis software from Head Acoustic. There were 5 psychoacoustic parameters assessed and each of them was assigned the same weigh of 20%, since we do not know the importance of individual psychoacoustic parameters. In the end, the rank order of the sound quality of washing machines was drawn up.

2.4. Subjective assessment

The implementation of the washing machines sound subjective assessment was carried out by 81 respondents (54 men and 27 women), who assessed the sound records of washing machines in three operation modes. 27 of 81 respondents was technical experts, people that are involved in washing machine development process. The average age of respondents was 44 years. The sounds were replayed to the respondents using the replay system from Head Acoustic. Each mode was assessed separately and the task consisted in awarding a score at a range between 1 and 10, where 10 means the best evaluation and 1 means the worst evaluation. The subjective assessment scale of the respondents is given in Table 2. Based on these assessments, the ranking order of the automatic washing machines was drawn up according to the respondents' evaluations of sound records individually for all three operation modes.

Table 2
Subjective evaluation scale.

Subjective magnitude	Noise characteristic	Amenity
1	Destructive noisy	Extremely intolerable
2	Very noisy	Intolerable
3	Noisy	Barely acceptable
4	Clearly heard	Acceptable
5	Heard	Endurable
6	Slightly heard	Controllable
7	Far off noise	Fair
8	Regular noise	Good
9	Hardly perceivable	Very good
10	Nothing perceivable	Excellent