Objective Evaluation of Interior Car Sound – the OBELICS project

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The consortium

The OBELICS project (BRITE-Euram 96-3727) has been carried out by a consortium of five companies and two universities, building three groups:

- Car manufacturers (Renault and CRF)
- Acoustic engineering and consulting: AVL, HEAD acoustics and LMS
- Research in Acoustics: Universities Oldenburg and Bochum

OBELICS has been coordinated by HEAD acoustics.

Introduction

Interior vehicle sound is an important factor for customers' satisfaction. To achieve an optimized product sound subjective evaluation methods as well as analysis and prediction tools have to be combined to provide reliable information relevant for the judgement of product quality and comfort situation.

Thus, the main objective of the OBELICS project was to understand the basis of sound language and sound perception and to derive methods and tools for an objective evaluation. The OBELICS project concentrated on the interior noise of vehicles due to its importance for the competitive situation of automotive industries in Europe. In a second step, the developed methods and tools can be transferred to other industrial branches.

This paper gives an overview on the work performed within the OBELICS project. More details are reported in related publications (see references).

Sound Database

A sound database has been built up that covers 14 driving conditions of 15 vehicles. It can be used as a reference for the development of new analysis methods for automotive sound engineering.

Subjective Testing: methodologies & results

As a result of the project, a library of subjective testing methodologies is available which will definitely serve as a "reference book" to engineers and developers in the field of sound engineering.

In addition, a four-language psychoacoustic dictionary has been set up, that will improve the communication between engineers and psycho-acousticians from different countries.

Three methods have been investigated for the subject-centered evaluation of different interior car-sounds:

- Semantic Differential method (SD).
- Multidimensional Preference Analyses.
- Associated Imaginations on Sound Perceptions method (AISP) [MES99].

The Semantic Differential for 15 items in 4 languages is now available for industrial applications. The AISP-method has been introduced to analyze systematically the understanding of emotional effects of sounds.

External (non-acoustic) sources of information contribute to the assessment of those perceived auditorily. A physical *sound event* is the most important but not the only criterion for the assessment of the *auditory event* which is in fact assessed by the listener. Thus cognitive aspects play an important role. Concerning environmental circumstances, road/driving situation, car class and type have been found as main dimensions of influence.

Loudness has been found as the dominating parameter. In preference tests a rank correlation coefficient of 1 was found between N_4-loudness of the cars and their preference rankings. After a suitable loudness equalization procedure had been established, a similarity test on loudness equalized stationary car sound samples was carried out to detect parameters 'behind' loudness. High correlation with pitch and tonality has been found. Thus, a reduction of tonality/pitch strength is strongly demanded.

The influence of intercultural differences on sound was investigated by Semantic Differential tests [BCSM00] as well as preference tests in three countries: Germany, Italy and France. The main results were the following:

- Good correspondence regarding the polarity profiles.
- Car sounds not equalized in loudness led to more distinct polarity profiles. Loudness can be regarded as a "perceptual amplifier", increasing the distinctness of inherent auditory features.
- Identical variances indicating comparable understanding of the verbal descriptors.
- Slight differences for some car sounds have to be regarded as a regional ("intercultural") effect.
- The Semantic Differential Tests validate comfort, power and sonority *as* essential factors.
- The factor analysis on the adjective pairs shows that in all three countries the adjective pairs unpleasant/pleasant, strenuous/relaxing, exciting/ calming, ugly/nice, rough/smooth and loud/soft explain the first factor. Concerning the second and third factor there are no similarities between the Italian, French and German data.
- AISP-clustering can give hints for naming of factors.

The investigation of sound quality perception of transient sounds has delivered informative results. Indeed transient sounds (as during acceleration phases) contribute for a large part on interior car sound quality perception so that it is necessary to develop adaptive parameters. It is necessary to keep on working in this field.

Objective descriptors

The relationship between the subjective evaluation and the objective parameters has been investigated. A number of psychoacoustic and physical parameters corresponding to auditory dimensions have been implemented and evaluated. Some of these parameters - also binaural ones - were proved to be significant. As a consequence a list of

the 26 most „important“ parameters could be established, which have to be optimized to fit with the reality of the automotive context.

As already mentioned above, loudness is the most important parameter in preference tests. Time varying loudness (including percentiles) can be regarded as useful for non-stationary sounds.

Tonality corresponds to unpleasantness and sportiveness. CRP corresponds to expensiveness. Irregularity corresponds to quality and expensiveness for idle noise.

The Relative Approach method [Ge96] has been found to be an excellent tool for the evaluation of disturbing time and/or frequency structures.

Research on binaural effects showed that distinct lateral sound sources in the car cabin should be avoided. Such measures definitely require binaural measurement procedures.

Using the results of the correlation analysis between subjective and objective evaluation a tool has been developed that selects those adjectives that relate most to the perception of a particular automotive sound.

Sound sets have been created using modified sounds with increase/decrease of tonality, high frequency content, and/or roughness. The results of expert tests using those sounds show that tonality, sharpness, articulation index and roughness are important in the judgement of unpleasantness.

New and advanced tools for sound design

The results of the subjective tests carried out within the project confirmed the need for reliable sound design tools, capable of creating specific “target sounds” aimed to well defined market populations.

For steady state sounds, a tool for harmonic / non-harmonic part extraction and recomposition has been developed. This allows to listen separately to sound components mainly related to the engine and sound components related to road and aerodynamic sources.

For transient sounds, a promising tool for sound design has been developed, called Time Domain Transfer Path Analysis (TDTPA) [Pon98, Pon00]. The tool is compatible to the established frequency domain Transfer Path Analysis (TPA) technique, and uses the TPA results for the order generation. The effect of different sound paths of engine-related sounds, and changes to the transfer characteristics can be simulated.

A psychoacoustic parametric synthesiser has been developed, aiming at the creation of artificial car sounds with controlled psycho-acoustic features, e.g. roughness.

Sound quality engineering, sound design as well as troubleshooting, is up to now based on laboratory playback systems using headphones. Investigations within the OBELICS project, however, show the context-sensitivity of subjective results. Users in the automotive field request more and more to implement a vibro-acoustic playback system in a car cabin (“SoundCar”, [GP98]). Future tools for sound design have to take in account multimodality in order to justify their relevance and insure their quality of use in subjective tests. SoundCar is a first step, but further work has to be done.

Optimization strategies

Using the tools developed within the project it is not yet possible to predict sound quality of a noise only from the analysis of its characteristics. For the creation of target sounds the results of subjective tests have to be included. Optimization criteria have been defined for stationary and transient conditions. Finally, no general target sounds can be defined. The target market and the sound image of the car manufacturer determine the definition of a target sound. It is also a marketing task to define it.

Transfer to other applications

The most useful instrumental measures obtained in this car context can be basically transferred to other products e.g. vacuum cleaners. However, for an optimal solution specifically valid verbal descriptors have to be newly evaluated for each new product. A successful way of doing this was shown in the OBELICS project.

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