Parameters Influencing the Benchmarking of Vehicle Interior Noise

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Introduction

The sound quality of vehicle interior noise has become a very important task for the acoustic engineer. As vehicles become more and more quiet, the customer's sensitivity to the acoustical comfort increases. On the one hand no disturbing noises should be heard, on the other the perceived sound quality should fulfill the expectations of the listener with respect to the sound design. For current and future needs the vehicle sound must act as a distinguishing criterion that supports the positive image of a car. In this context the following characteristics of sound are useful:

- Sound is informative, it includes information of quality, functionality
- Sound implies a certain image, such as luxury, sportive or cheap
- Sound may be identified, it may be used for corporate or product sound purposes

In consequence, sound quality is an essential part of vehicle quality. But besides the sound the contribution of vibration is not negligible. The passenger of a vehicle has to be seen as part of a vibro-acoustical system. Consequently, the subjective judgement of pleasantness or sound comfort is influenced by both sound and vibration. For a task-oriented proceeding in sound design it is absolutely necessary to consider these aspects. The performance of benchmarking tests of vehicles firstly requires an analysis for which market – that means for which relevant customer – and in which competition this vehicle stands. The performance of a simulated modification in real time for the adaptation of the acoustical features to the new target sounds is very important.

The passenger of a vehicle must be regarded as part of a vibro-acoustic system. Correspondingly, the subjective judgment which passengers make about their impression of levels of acoustic comfort encompasses both sound and vibration. Indeed, a task-related approach to sound design demands consideration of both of these factors. Achievement in this field depends on obtaining knowledge about the interaction between sound and vibration and how these factors impact subjective evaluation. Further requirements are an appropriate playback device and suitable analysis (and signal processing) software.

Rating comfort in the interior of vehicles

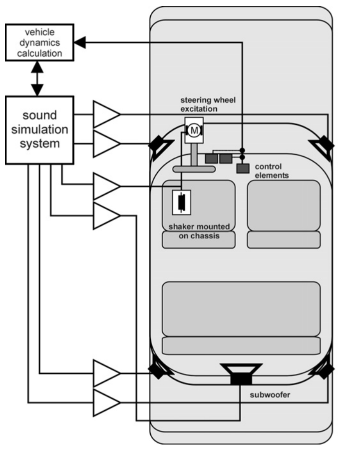
The challenge of integrating auditory perception and tactile and visual impressions is based on the recognition that a human being does not evaluate his environment on the basis of a single dimension. In fact, it is rather a question of the interplay between the various levels of perception. In this field, developments in the area of „virtual reality", adapted to the special requirements of acoustic and vibration environment design, can make a meaningful contribution. Vibrational comfort greatly impacts the well-being of vehicle passengers and greatly enhances road safety by reducing the level of distraction to which drivers are exposed [1].

In general, via the source, car body and vehicle interior, transmission may impact the body and ears of passengers. Judgment of the sound quality of a car and its components is based on the resulting vibro-acoustic exposure.

At present, detailed research, able to provide a full scientific explanation, has not yet been forthcoming. Investigation has revealed that if the vibration level remains within the range of the perception threshold there is a trade-off phenomenon between sound and vibration: Loudness is judged to be greater when vibration is present in such a situation [2].

Appropriate vibro-acoustic playback may include airborne sound via headphone(s), low frequency sound below 150 Hz via subwoofer(s) and vibrations at the steering wheel and seat via excitation devices.

Figure 1 shows the set-up of a system of this kind.



Configuration of a sound simulation subsystem in a car, including the vibroacoustic playback system as well as elements necessary to achieve an interactive virtual environment for driving simulation: control elements, vehicle dynamics simulation, sound simulation using binaural playback for not moving sources and binaural synthesis for moving sources.

Figure 1: Arrangement for sound and vibration reproduction in a car cabin

The main advantages of „SoundCar" are:

- Playback of a combined vibro-acoustic situation in a realistic environment
- Real-time comparison of several vibro-acoustic situations without the need to "switch" between different test vehicles
- Fast and cost-saving evaluation of greater reliability

The complete procedure for operating a system of this kind may include these steps:

- Preliminary multichannel measurements with capture of binaural signals
- and acceleration at the points subsequently excited
- Multichannel playback and evaluation of the vibro-acoustic situation
- Digital signal synthesis (i.e. filtering) of particular signals

- Playback of modified signals and comparison to baseline version
- Optimization of the vibro-acoustic situation using the option of time and/or synchronous sample comparison

First research tests completed for the European research project OBELICS (Objective Evaluation of Interior Car Sound) [3] have shown that the use of SoundCar may result in more reliable sound characteristic and quality evaluation. Further investigations have been completed in a number of projects. The following chapter outlines the results obtained.

Virtual Vehicle

Ability to both feel and hear the results of engineering decisions via a "virtual car" - simultaneous engineering - can significantly shorten vehicle development time. Sound quality and discrete vibration at the driver’s position may be predicted and "driven" before the first prototype is built. Although sound cannot yet be predicted in an unknown chassis, the sound and vibration behavior resulting from a new engine, never previously installed in a given vehicle, may be predicted, heard binaurally and felt in an interactive "drivable" simulation based on transfer path analysis. Such a simulation which includes the binaural sound information and discrete vibration of steering wheel and seat, can also include wind and tire noise to determine if certain engine contributions in sound and vibration may be masked. The method involves use of two technologies in conjunction: Binaural transfer path analysis (with vibration transfer path analysis) and a real-time interactive multichannel acoustic and vibration simulation system. From transfer path data the simulation environment permits interactive control from throttle position of relevant vehicle behavior including load, gear ratios, vehicle mass, etc. providing running acoustic and vibration simulation. The user can change chassis impedances, etc., and "drive" the resulting behavior.

Concept of a Sound Simulation System

The **virtual vehicle** is doubtless one of the most interesting applications of virtual environment technologies. The ‘driver’ feels immersed in the virtual world if he/she receives plausible feedback to his/her actions. The most important feedback components are inertial, visual and acoustic including vibrations. Normally a ‘mixed reality’ scenario is implemented: A real passenger compartment with real control instruments is combined with a simulation of inertial, visual, acoustical and vibrational feedback. For the present discussion the inertial aspect is not involved and will not be covered. For simulation of the driving situation the following sound components must be taken into consideration [4]:

- Engine sound, dependent on engine type, speed and load
- Tire sound, dependent on tire type, speed and road conditions
- Wind noise, dependent on speed
- Sounds produced by other dynamically moving objects, especially other vehicles. Those sounds depend on vehicle speed and orientation
- Background sounds, including interior and exterior sources

Depending on requirements, certain simplifications may be made concerning generation of the different sound components. If the system is to achieve an auditory impression very close to that perceived in a specific real vehicle, a lot of specific acoustic and vibration recordings or simulations from transfer path measurements of that vehicle must be stored in a local database. If a ‘good impression’ is sufficient, more general sounds may be used instead. In both cases synthesized sounds can be included. For sound design applications, additional tools for interactive manipulation of sound components are required.

Sound Design Tools

For sound design applications, the following tools can be realized online during simulation:

- Changing the complete sound scenario intuitively, simply by driving virtually
- A/B comparison between different engines measured inside passenger cabins
- A/B comparison between wind and tire noises
- Online filtering of those three sound components
- Recalculation of a binaural transfer path synthesis model as described above
- Binaural Simulation of interior car sound for different engines measured on a test rig using data from binaural transfer path analysis. For this application a correction function must be applied to the test rig data, which considers the structure-borne coupling of the engine at the test rig and the room acoustics of the engine compartment

The big difference compared to well-known laboratory sound design tools is that all sound perception effects are perceived within a very realistic context, namely driving a virtual vehicle.

Conclusion

For the correct prediction of sound quality inside of a vehicle it is necessary to consider the interaction between what the listener can hear and feel, both with consideration of the expectations of the listener. For the investigation of the sound design it is necessary to have a direct reaction of sound and vibration of the action the test person has done. With respect to low frequency components the subjective perceived sound quality depends on the vibration the listener can feel at steering and seat. Based on two European supported projects it was possible to develop a tool which predicts on the one hand the sound and vibration relationship inside of a car based on measurements at an engine test-rig and on the other hand to reproduce sound and vibration in dependence on the action of the test person.

References

[1] M. Mitschke, L. Kirschke, Untersuchung über das Schwingempfinden und die Schwingbeanspruchung des Menschen in fahrenden Personenkraftwagen, Deutsche Kraftfahrtforschung und Strassenverkerhrstechnik Heft 202, 1970 in Braunschweig

[2] Y. Tamura, M. Hiraga, The Effect of Low Frequency Vibration on Sound Quality of the Automobile Audio System - Proposal of a New Automotive Audio System

[3] W. Krebber, H.W. Gierlich, Acoustical Feedback System for Virtual Vehicles. ATA 1997, 26.-28.02.1997, Florenz, Nr. 97A1045