Sound Quality Assessment Using Wave Field Synthesis.

Clemens Kuhn[1], Gordon Seitz[2], Renato S. Pellegrini[1], Matthias Rosenthal[1]

[1] *sonic emotion ag, Eichweg 4, CH-8154 Oberglatt, Schweiz, info@sonicemotion.com*

[2] *Volkswagen AG, Konzernforschung, Fahrzeugdynamik K-EFFD/H, Postfach 1499, D-38436 Wolfsburg*

Introduction

An approach to sound field reproduction for subjective assessment of in-car sound is described in this paper. Wave field synthesis enables a perceptively correct reproduction of spatial audio without headphones. This allows a convincing experience of audio environments and enables reliable results in subjective tests especially with untrained test persons.

Virtual prototyping has become a common NVH engineering tool to reduce development time and to increase prediction capability in product development processes. A number of simulation systems have been presented up to now and field reports have been published (e.g. [Janssens et al., 2004], [Allman-Ward et al., 2004], [Sottek et al., 2005]).

In the past years, several authors reported on the influence of spatial audio reproduction for the assessment of product sound quality. Investigations on binaural reproduction methods have shown influence of spatial audio reproduction on physiological responses as well as perceptual attributes such as loudness, sharpness roughness or unpleasantness [Bodden, 1993], [Hempel, 2001], [Chouard, 1997]. Comprehensive hearing models for perceptive attributes of interior car sounds affected by spatial reproduction have not yet been developed. Still, the existing results give a clear indication that spatial reproduction influences the judgement of product sound quality and gives reasons for spatialisation in simulation environments in order to guarantee reliability of evaluations and target setting processes.

Quality of spatial reproduction

The aim of a perfect simulation would be, in principle, to approach the real impression of an environment at the best, such that the simulation will be undistinguishable from the real environment.

In any case an auditory virtual environment (AVE) will never be able to simulate such an authentic perception as a given real environment since technical restrictions, limited processing capacities, measurement errors, etc. will degrade the quality of the reproduction. Therefore, several authors have considered quality features of AVEs in order to give relative measures for a classification of reproduction capabilities in a certain context. We have to consider quality of the spatial reproduction in relation to the purpose of the environment. The spatial audio reproduction for an interior vehicle sound should provide the same perception on determinant parameters of sounds than a real environment. One important aspect of sound reproduction quality is the ability of the system to immerse the listener into a virtual environment. This feeling of "presence" within a virtual environment is a key aspect especially when untrained listeners are asked to judge intuitively certain sounds (e.g. to include the customer's opinion into the devolpement process). Objective investigations on the quality of spatial reproduction systems are currently in progress and their comprehensive description would go beyond the scope of this paper. The reader is referred e.g. to [Pellegrini, 2001], [Zacharov at al., 2001], [Lombard et al., 1997]).

Sound reproduction systems

Most vehicle sound simulation systems presented up to now use diotic or dichotic (binaural) reproduction over headphones or stereophonic loudspeaker reproduction e.g. with a 4.1-set-up. The aim of a binaural sound representation is to provide ear input signals using HRTFs to create a spatial impression of the virtual environment. The main advantage of this approach to provide in theory a localization of sound sources in all three spatial dimensions.

In practice this approach shows several drawbacks. The localization is disturbed by front-back confusions, out-of-head localization is limited and distance perception does not necessarily match the intended real image [Blauert, 1997]. One solution can be to provide head tracking for the binaural reproduction. Still, the feeling of wearing a headphone remains and reduces the immersion into the virtual environment.

To overcome such problems, the authors propose to use wave field synthesis for the reproduction of sounds in such AVEs. The technology was first presented by Berkhout in the 80s [Berkhout, 1988] and is available today for practical implementations and system integration.

Wave field synthesis (WFS) is based on the Huygens' principle and is able to reproduce holographic sound images and homogenous sound fields without sweet spot. Wave field synthesis creates the effect of "perspective" for the reproduction of sound sources. The sound field closely approximates the field emitted by a real source. The listener can freely move his head within the sound field as if in a real vehicle. In the past years a number of reproduction methods have been developed to enable compatibility with existing sterephonic or binaural recordings. They provide the reproduction of such audio material using so called "plane waves" to enlarge the stereophonic "sweet spot" to an extended listening area. The sound field becomes very homogenous and immerses the listener into the virtual environment. From a practical point of view, restriction of the sound field reproduction to a horizontal line array of loudspeakers seems reasonable. On one hand it allows still a clear out-of-head localization. On the other hand, first

experiences give an indidcation that cues from the median plane are not necesserily required for a plausible simulation.

Implementations

WFS requires a certain minimum number of loudspeakers to create a plausible sound field. "Desktop"-systems are feasible starting at 24 loudspeakers surrounding the listener.

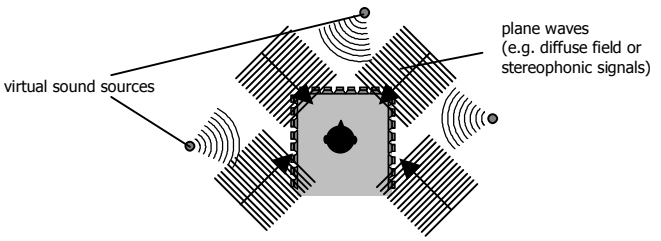

Figure 1: WFS set-up: holophonic reproduction using point sources and diffuse field or sterephonic reproduction using plane waves.

Also more sophisticated solutions have already been implemented with loudspeaker arrays integrated into the car. The system is driven by a parametric model of car sounds controlled by rpm, throttle and speed. A network layer has been implemented to control the positioning of the virtual sound sources from the driver interface. Further details can be found in [Pellegrini et al. 2005]

Figure 2: Full vehicle driving simulator with WFS set-up

Conclusions, Future Work

First experiences have shown that wave field synthesis provides an intuitive tool for sound quality assessment. Out-of-head-localisation and immersion are improved, headphones are not required. Further investigations on practical implementations and their evaluation for car sound applications are in progress.

References

[Allman-Ward et al., 2004] Allman-Ward, Marc; Williams, Roger; Dunne, G; Jennings, P.: "The evaluation of vehicle sound quality using an NVH simulator." Internoise 2004, 33rd International Congress and Exposition on Noise Control Engineering, Prag, Czech Republic, August 22-25 2004

[Berkhout, 1988] A .J. Berkhout: "A holographic approach to acoustic control", Journal of the Audio Eng. Soc., Vol. 36, pp 977-995, 1988

[Blauert, 1997] Blauert, Jens: "Spatial hearing: The psychophysics of human sound localization", revised edition. Cambridge, MA, 1997

[Bodden, 1993] Bodden, Markus: "The importance of binaural hearing for noise validation", "Contributions to Psychological Acoustics." Results of the 6th Oldenburg Symposium on Psychological Acoustics; Bibliotheks- und Informationssystem der Carl von Ossietzky Universität Oldenburg, 537-554, Oldenburg, Germany, 1993

[Chouard, 1997] Chouard, Nicolas: "Loudness and unpeasant perception in dichotic conditions." PhD thesis, Université du Maine, Le Mans, France, 1997

[Hempel, 2001] Hempel, Thomas: "Untersuchung zur Korrelation auditiver und instrumenteller Messergebnisse für die Bewertung von Fahrzeuginnenraumgeräuschen als Grundlage eines Beitrags zur Klassifikation von Hörereignissen", PhD thesis, Technical University-Berlin, Berlin, Germany, 2001

[Janssens et al., 2004] Janssens, Karl; Coomans, Hans; Belghit Ismaël; Vecchio, Antonio; Van de Ponseele, Patrick; Van der Auweraer, Herman: "A Virtual Sound Synthesis Approach for On-line Assessment of Interior Car and Aircraft Noise." ICSV Conference, St. Petersburg, Russia, July 2004

[Lombard et al., 1997] Lombard, Matthew; Ditton, Theresa: "At the Heart of It All: The Concept of Presence." Journal of Computer Mediated-Communication [On-line], 3(2), 1997 Available at `http://jcmcindiana.edu/vol3/issue2/lombard.html`

[Pellegrini, 2001] Pellegrini, Renato S.: "Quality Assessment of Auditory Virtual Environments." Proceedings of the 2001 International Conference on Auditory Display, Espoo, Finland, July 29 - August 1 2001

[Pellegrini et al. 2005] Pellegrini, Renato S.; Rosenthal, Matthias; Kuhn, Clemens: "Wave Field Synthesis: Open System Architecture using Distributed Processing." Proceedings of the Forum Acusticum 2005, Budapest, Hungary, August 29 - September 2 2005

[Sottek et al., 2005] Sottek, Roland; Krebber, Winfried; Stanley G. (Randy): "Tools and Methods for Product Sound Design of Vehicles." Society of Automotive Engineers, Proceedings of the SAE Noise & Vibration Conference, Traverse City, MI, USA, May 16-19 2005

[Zacharov et al., 2001] Zacharov, N.; Koivuniemi, K.: "Unravelling the perception of spatial sound reproduction: techniques and experimental design." Audio Engineering Society, Proceedings of the AES 19th International Conference on Surround Sound, pp. 272-286, Elmau, Germany, June 21-24 2001.