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MAKING SOUND QUALITY AUDIBLE

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1. INTRODUCTION

Product sound quality [1], [2], [3], is of great interest to vehicle manufacturers. Especially interior vehicle noise is targeted by NVH- (noise, vibration and harshness) engineers to make it sound more acceptable or even pleasant. Any enclosure into which sound is radiated will impose its frequency response onto this sound. However, the effect of the enclosure on perceived sound quality is debated among researchers. Moore [4], p.296, states that "...room acoustics have relatively little effect on the perceived quality of reproduced sounds". It will be shown in this paper that enclosures have considerable effect on the sound quality of reproduced sound. Virtually no literature is available on the passive acoustic behaviour of the vehicle cabin. Because the human ability to memorise acoustic environments is fairly moderate, the method is to listen to anechoic music convolved with the impulse response of two controversial acoustic environments and compare them with the original 'dry' piece of music [5]. Since the use of loudspeakers would introduce coloration from the room into which they radiate, the comparison should be made with headphones. The two acoustic enclosures investigated here are a small semi-reverberant chamber and the vehicle cabin of a middle-class car.

2. THE ACOUSTIC IMPULSE RESPONSE OF AN ENCLOSURE

The acoustic impulse response of an enclosure gives information about the time domain and frequency domain characteristics of the 'system'. It assumes LTI (Linear Time Invariant) behaviour. If the enclosure under investigation already exists, then the interior space is excited by some excitation signal, which may or may not be an impulse, and the response of the room is recorded onto tape or hard disk. Alternatively, the room impulse response could be obtained artificially by imitating the acoustic decay behaviour of the enclosure in software. Simulation software to model room responses is now available commercially [6], [7], [8]. The physical or artificial modelling of binaural room acoustics is known as auralization.

An excellent introduction into auralization is given in [9]. Another related field where the impulse response is extensively used is 3-D sound [10]. In 3-D sound pre-recorded HRTFs (Head Related Transfer Functions) [11] are applied to music presented via headphones in computationally demanding real time. Auralization can create the impression to be in a virtual room or space. In 3-D sound, however, the parameters 'sound source localisation' and 'externalization' come into play as well. An image often used to illustrate 3-D sound is that of a buzzing bumble bee flying around your head, generated under headphone conditions [12]. In this paper, no binaural recording technique has been applied. The effect of the pinna, head and torso represented by the HRTF is not significant at low frequencies.

3. PROCEDURE

A single channel impulse response has been obtained with a well known 12-bit MLS (Maximum Length Sequence) audio card which is fitted to an IBM-PC. If the impulse response of the vehicle cavity is recorded onto a computer, it can subsequently be used as a filter to make the acoustics of the passenger cabin audible. The trick is to use music which has been recorded in an anechoic chamber and convolve or filter it with the impulse response of the enclosure under investigation.

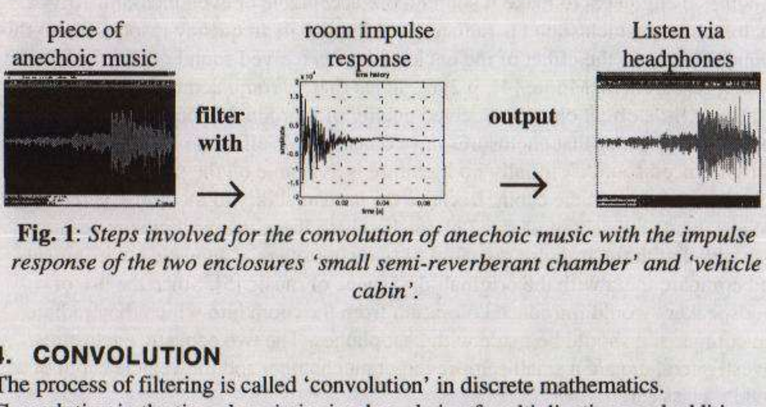

Fig. 1: *Steps involved for the convolution of anechoic music with the impulse response of the two enclosures 'small semi-reverberant chamber' and 'vehicle cabin'.*

4. CONVOLUTION

The process of filtering is called 'convolution' in discrete mathematics. Convolution in the time domain is simply a chain of multiplications and additions and this can be a computationally lengthy process and a fast processor therefore is an advantage. The convolution operation has been performed in MATLAB [13] running on a conventional IBM-PC. The convolution process of music [5] of 15s length with a 0.1s long impulse response can take several hours. However, there are fast convolution algorithms available which take advantage of FFT routines which can greatly reduce the processing time. Alternatively, an all-pole model with a much shorter filter order than the all-zero representation of the room impulse response could reduce processing time to seconds even when time domain processing is chosen.The piece of music used in this paper is sampled at 44100 Hz and so is the impulse response of the 'rooms'.

5. RESULTS

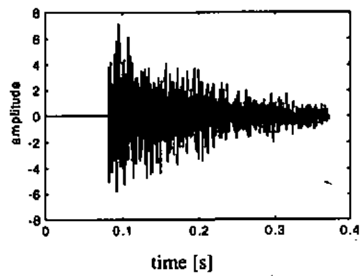

Fig. 2: *Impulse response of a small reverberant room to a MLS excitation. The amount of reverberation is considerable.*

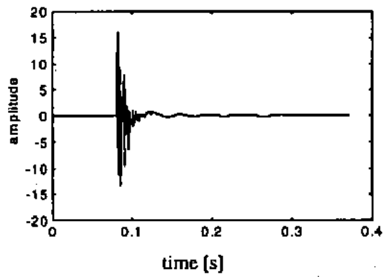

Fig. 3: *Impulse response of a car cabin to a MLS excitation. The energy dissipates very swiftly. There is hardly reverberation present.*

Experiment No.	Filter for anechoic piece of music	Excitation method to obtain the impulse response	Subjective impression when listening to the convolved music through headphones
(1)	-----	-----	*reference is the original anechoic piece of music;*
(2)	impulse response of small reverberant room	Maximum Length Sequence	sounds bright and reverberant; gives a feeling of spaciousness;
(3)	impulse response of vehicle cabin	Maximum Length Sequence	sounds dark and dull, like muffled

Table 1: Result of convolution of anechoic music with the enclosure impulse response

6. DISCUSSION

The effect of the chosen enclosure types on anechoic music is dramatic. The vehicle cabin obviously attenuates high frequencies effectively. Low frequencies seem to dominate. Compared to the semi-reverberant room, little or no reverberation occurs. The phase response of the vehicle cabin impulse response seems to be minimum phase. Minimum phase means no all-pass components are present and therefore phase seems to have little effect on perception for the vehicle impulse response. The effect of unevenness in the excitation spectrum, for instance due to a non-flat frequency response of the loudspeakers reproducing the MLS sequence, has been tested by convolving or filtering anechoic music with the impulse response of an anechoic chamber. Little or no difference can be heard when compared with the 'dry' piece of music. In other words, equipment imperfections can be neglected.

7. CONCLUSIONS

The acoustic impulse response carries important information about the acoustic behaviour of enclosed spaces. By convolving anechoic music with the acoustic impulse response of a vehicle cabin the peculiarity of vehicle interior acoustics have been made audible. Improved situational awareness can be created for the interior space 'vehicle cabin'. Direct sound from the engine and other sources will be far more important than reflected sound. As a caveat, it has to be born in mind that there is no unique impulse response because of its dependence on factors like source-receiver position and excitation method.

8. ACKNOWLEDGEMENTS

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