The integration of Sound Quality Equivalent models in a real-time Virtual Car Sound environment

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Introduction

One of the main concerns in the development of new cars is the acoustic comfort for driver and passengers. Today, the use of NVH engineering and sound quality tools in automotive development is well-accepted, but their application is mainly restricted to the refinement and troubleshooting of physical prototypes. This is, of course, a very important and necessary step, but it is time-consuming and quite late in the development stage.

But what would happen if you could listen to your car in a much earlier stage (even before the physical prototype is available) and if you could modify and optimize the sound while driving in real-time in your virtual environment? There is no doubt that this would provide enormous advantages and a considerable reduction in production time and costs.

Virtual Car Sound environment

In this context, LMS started up an innovative project in which an interactive, real-time Virtual Car Sound (VCS) environment is developed. This sound synthesis environment allows the user to (1) drive interactively by using throttle, brake and gear, (2) to evaluate in-vehicle acoustic comfort in steady-state and transient conditions, (3) to study the perceptual influence of individual and groups of signal components and (4) to simulate structural modifications using either experimental or hybrid models.

In VCS, two real-time processes are running in parallel (figure 1). The first process is the vehicle model simulator. This process implements a vehicle model that according to a throttle, brake and gear input, generates the evolution of rpm and vehicle speed. The second process is the real-time sound generator. This process synthesizes the sound starting from the rpm, throttle and vehicle speed. Therefore, it makes use of a compact Sound Quality Equivalent (SQE) model and of Head Related Transfer Functions (HRTF's) if binaural sound has to be generated starting from a monaural model.

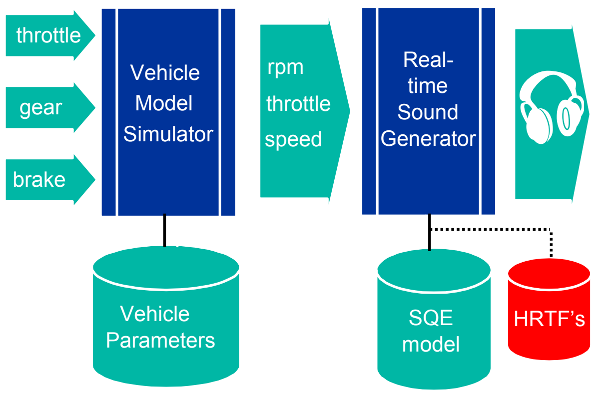

Fig. 1: Sound synthesis concept

VCS includes charts to represent the SQE model, to define the vehicle model parameters, to drive and replay and to support analysis:

SQE model

The SQE model is a compact model that synthesizes in-vehicle sound with equivalent sound quality perception. Engine noise is described by a number of orders and 1/3th octave bands for the background noise. The amplitude and phase of the orders and the level of the 1/3th octave bands are modelled in function of throttle position and rpm. Road noise is also described in 1/3th octave bands, but this time with levels in function of vehicle speed. In VCS the SQE model components are represented in a tree structure and can be displayed.

Order contributions and 1/3th octave bands can be muted and reactivated while driving. This gives you the possibility to examine which signal components are contributing the most to the perceived loudness.

Furthermore, real-time editing operations are supported. Different sorts of real-time modifications are possible. Both amplitude (add offset, multiply with factor, rescale to a constant value, linearize, smooth data, remove peaks,...) and phase (replace by a constant phase, change slope,...) can be modified. This functionality allows you to play what-if games where you virtually modify the sound and evaluate the sound quality in one shot. By doing so, you can try to design an optimal target sound.

vehicle model

In addition to the SQE model, a vehicle model is implemented in VCS. The vehicle model is a simplified model that includes a number of user-defined parameters such as car mass, cross-section, cx-coefficient, rolling resistance, engine torque information and gear coefficients.

drive and replay mode

In VCS, the driver can accelerate and decelerate freely by interactive control of the vehicle's throttle, brake and gear. Digital counters give a continuous feedback of rpm and vehicle speed. Gear shifts and driving in cruise control mode are also supported. The use of keyboard controls facilitates the driving process.

The time-histories of throttle, rpm and vehicle speed can be stored and replayed at any time. There is also the possibility to record the synthesized sound for further analysis and validation. VCS also supports the replay of time structures (e.g. wipers sound, radio,…) when driving. Screen shots of the drive and replay mode are given in figure 2.

real-time graphs

Graphs are included for real-time display of car model variables (rpm, speed,…), SQE model components (orders, 1/3th octave bands) and FFT spectra. The graphs are updated every 0.15 seconds. Typical screen shots are shown in figure 3.

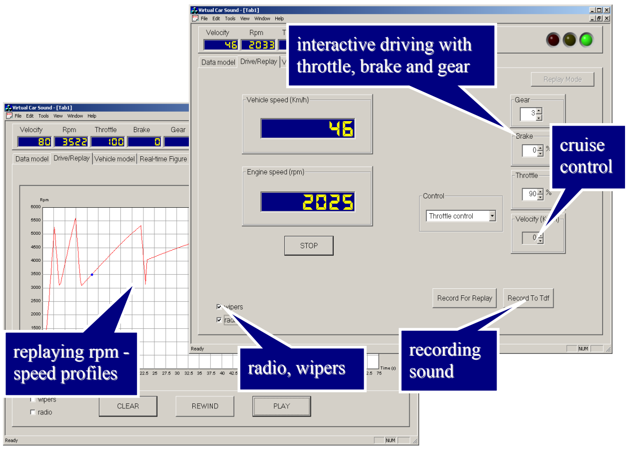

Fig. 2: Drive and replay mode

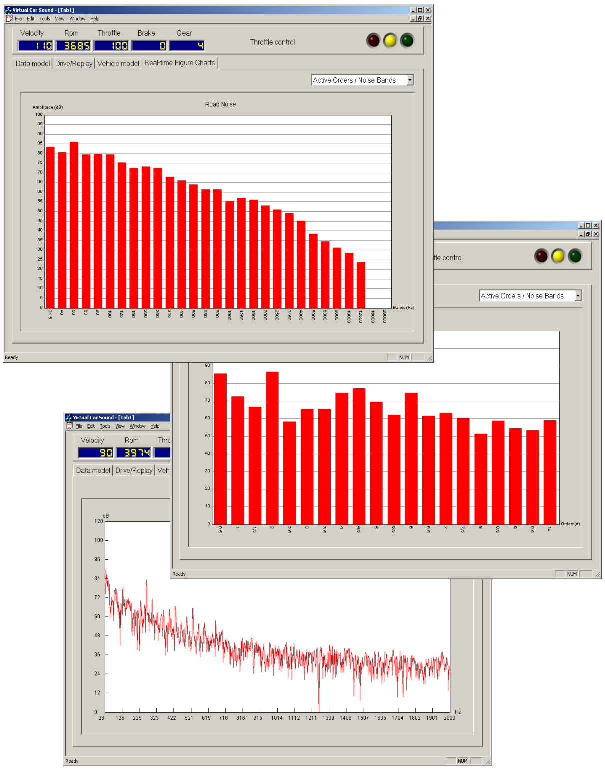

Fig. 3: Typical examples of real-time figures (1) upper graph: road noise 1/3th octave bands; (2) middle graph: engine noise orders; (3) lower graph: real-time FFT spectrum

Real-time structural modifications

With the SQE models that we discussed so far, it is not possible to do real-time *structural* modifications while you are driving in your virtual environment. To make this possible, the VCS environment was extended with an engine noise Transfer Path Analysis (TPA) module. In engine noise TPA in-vehicle sound is considered as the sum of partial pressures. Each partial pressure is associated with a transfer path that is characterised by a force input and a frequency response function (FRF).

Within VCS an engine noise TPA model is represented in two ways: (1) in a transfer path tree and (2) in a signal component tree. The tranfer path tree, on the one hand, represents the engine mount stifness, the FRF and the accelerations at both sides of the engine mount, and this for the different transfer paths. The signal component tree, on the other hand, represents the resulting partial pressure contributions of all transfer paths. Signal components as well as transfer paths can be activated and muted.

Very interesting is the ability to visualise the partial pressure contributions of the individual transfer paths per order in real-time (figure 4, upper graph). This is, for example, very useful to study booming noise. You can see very quickly which transfer paths are causing the booming effects.

Once you know the critical transfer paths, you can start to modify them in order to meet the sound quality target settings. Engine mount stiffness as well as FRF characteristics can be modified in real-time (figure 4, lower graph). It is clear that these structural modifications provide an enormous advantage towards the optimisation of in-vehicle acoustic comfort.

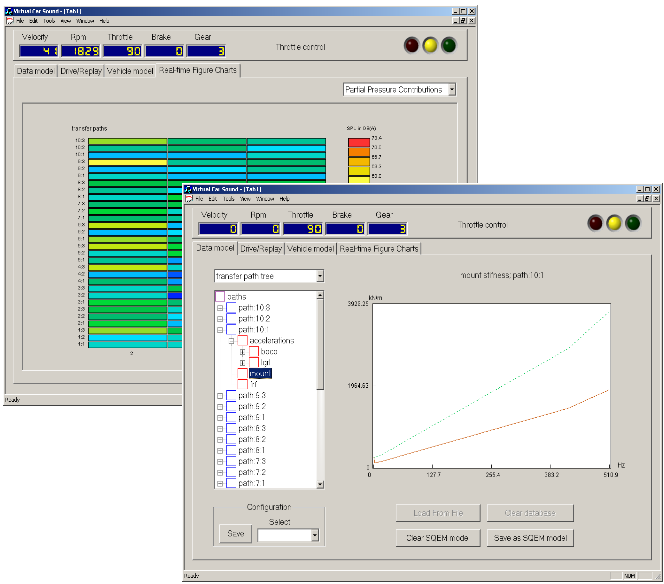

Fig. 4: Engine noise TPA module in VCS: (1) upper graph: real-time display of partial pressure contributions of individual transfer paths per order; (2) real-time engine mount modification.

Conclusions

1. an interactive, real-time sound synthesis environment was developed for vehicle applications
2. within VCS engine noise and road noise are synthesized with equivalent sound quality perception, without clicks and high frequent chirps and without timing problems
3. signal components (orders, 1/3th octave bands) and transfer paths can be muted and re-activated while driving
4. real-time modifications of engine mounts and FRF's are supported and provide enormeous possibilities towards the optimisation of in-vehicle acoustic comfort.