Driving Sound Simulator – a Universal Tool in the Development Process

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Introduction

In the development process of a vehicle, experience is more meaningful than looking at diagrams. It is easier to convince colleagues, management and non NVH experts if they can hear and feel the difference.

A driving sound simulator is an interactive playback of binaural sounds and vibrations of powertrain, tire-road and wind noise for many applications like benchmark, target sound setting and decision-making-support [1].

Simulation Concept

In an interactive simulation, the user drives the virtual vehicle with gear lever, throttle and brake pedal. A driving dynamic model of the vehicle calculates the resulting operating condition consisting of rpm, load and speed. The corresponding powertrain, tire-road and wind noise are played back (Figure 1).

The driver selects various engines, road surfaces and wind noises from a sound database. The user can switch sound sources on and off, modify the level, and manipulate the sounds using filters while driving. The simulation concept can be extended by Binaural Transfer Path Analysis.

A driving simulator is a scalable solution (Figure 2). The entry level is a desktop simulator with calibrated and aurally accurate headphone playback, a monitor for the visualization of the road and pedals for the interaction. A basic visualization is necessary for the speed perception. It is recommended to use a straight road because the driver should concentrate on the sound and not on driving and staying on the road in a virtual world.

The next level is a fixed-base simulator with additional seat and steering wheel vibrations. What you here and feel is what you judge. The perceived acoustic quality is linked to the vibrations [2]. A sports car without vibrations might be lifeless but the comfort of a luxury car might be destroyed by inappropriate vibrations. A simplified setup (SoundSeat) or a complete vehicle cabin (SoundCar) can be used. Adding the context, the look and feel of a real vehicle, creates a higher immersion.

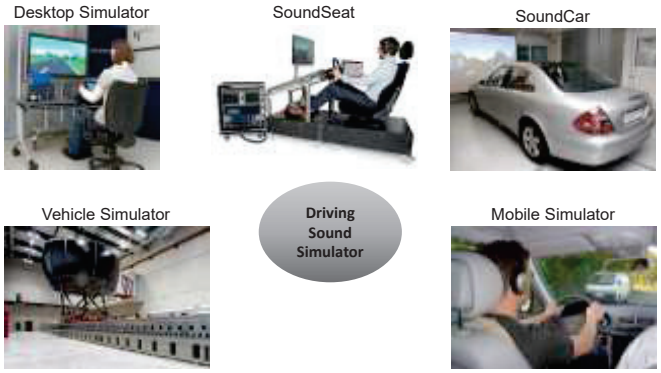

Figure 2: A driving sound simulator is a scalable solution.

In a mobile simulator, the system is built into a real car. The driving parameters are transmitted via CAN bus and the sound is played back using ANC headphones. This gives the best driving experience – a real car in the real world - but the vibrations cannot be changed so the host and virtual vehicle should belong to the same class.

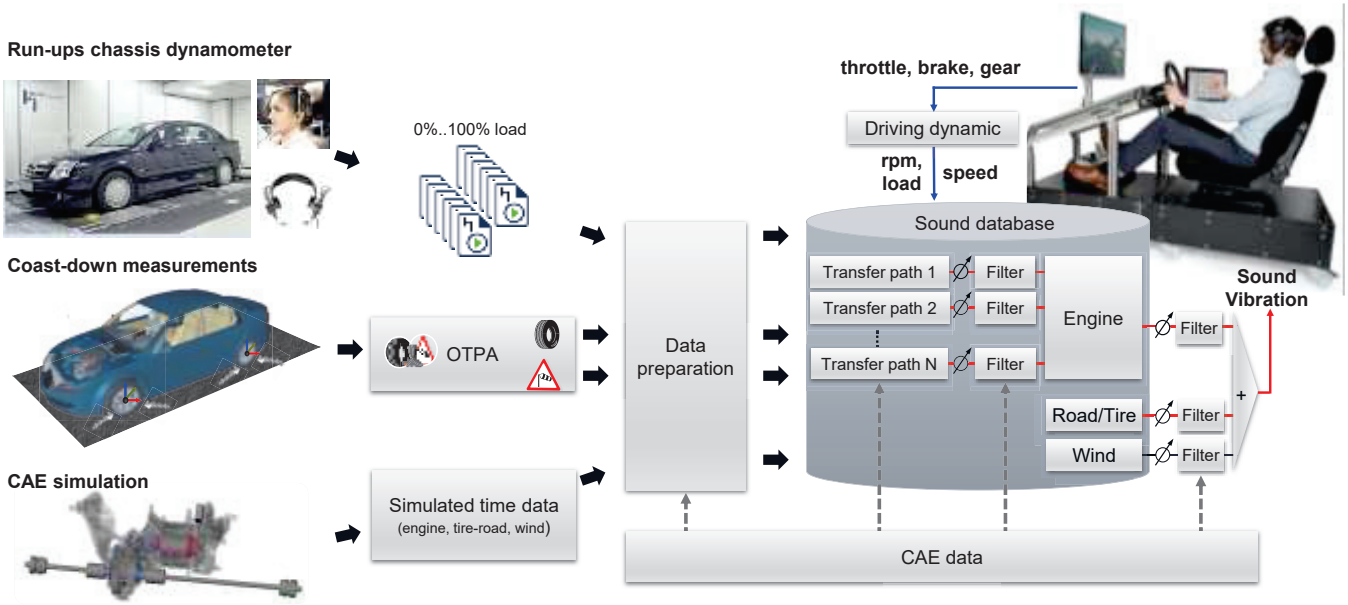

Figure 1: Simulation concept of a driving sound simulator for interactive playback of binaural sounds and vibrations of powertrain, tire-road and wind noise

The driving sound simulator can be integrated as a subsystem in a full vehicle simulator with a moving platform. The vehicle simulator covers the visualization of the virtual world, the vehicle dynamics model and the driving controls. The driving sound simulator receives continuously the driving parameters like speed, rpm and load via a software interface and creates the corresponding sounds.

Dataset generation

A driving sound simulator needs datasets for powertrain noise, tire-road and wind noise. Binaural recordings with an artificial head or binaural headsets are used to achieve an aurally accurate playback. If the simulator hardware supports vibration playback the accelerations at steering wheel and seat rail are recorded, too.

The powertrain noise is measured during run-ups on a chassis dynamometer for all load conditions from 0% to 100% throttle in several steps. In a preprocessing step, an engine dataset is prepared from these recordings.

An authentic tire road noise cannot be measured on a dynamometer. Coast-down measurements on a real road are used instead. On a test track the car is accelerated up to top speed and the engine is switched off or at least put into neutral gear. The interior noise and signals of additional sensors at the tires, microphones at the tire inlets and outlets, as well as triaxial accelerometers at the wheel hubs are recorded simultaneously. The interior noise is separated into tire-road noise and wind noise using the OTPA method [3] before the data is prepared for the simulator. CAE data can be used during the simulation or in preprocessing steps (see Table 1).

Applications

A driving sound simulator is a useful tool for various applications in the automotive development process.

Benchmark

In a benchmark, the acoustic performances of different vehicles are compared to check if the targets are met or to define new targets for the next generation.

The requirements for the simulator are not to produce just an authentic but more or less arbitrary sound which achieves a desired effect like in a video game. The far more challenging task is to simulate the most accurate replication of the real car possible.

After the datasets of the necessary vehicles have been measured and prepared, the test subjects evaluate different engines or tires, competitor vehicles and development stages during a virtual test drive.

The benefits of a driving sound simulator are: The driver can switch the car sound immediately and hear even small differences. It is weather independent and there is no need for a test track and physical cars at least during the benchmark study. The test persons “control” the sound they hear. It is interactive instead of just listening. It is a big difference between listening to boring run-ups in a dark listening studio and driving a car yourself.

Virtual prototype

High costs, shorter development cycles and an increased number of derivatives are the reasons that car manufacturers are reducing the number of prototypes. A virtual prototype based on the combination of test data and CAE data using Binaural Transfer Path Analysis (BTPA) can be experienced in a driving sound simulator to judge the sound quality as early as possible.

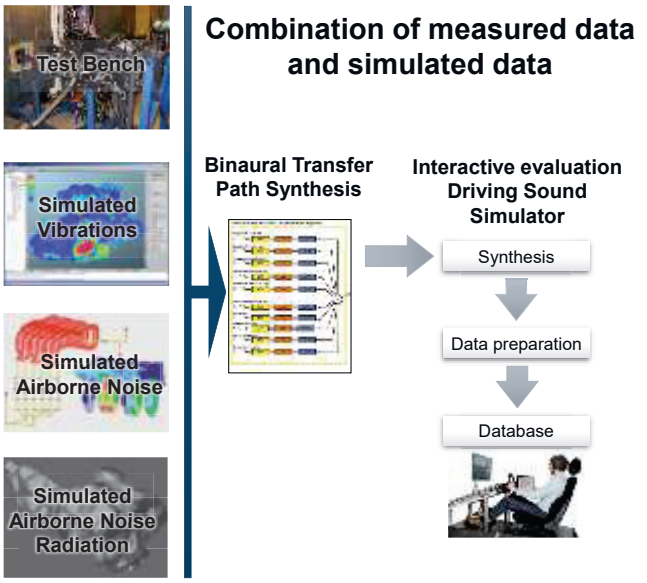

Figure 4: Binaural Transfer Path Synthesis combines measured and simulated data. The virtual prototype can be experienced in a driving sound simulator

Table 1: Integration of CAE data

	simulated…	
during simulation	...changes of measured orders	order tracking filter (level vs. rpm vs. load)
	...insulation package	highpass, lowpass, bandpass filter
	…new orders	order generator (level and phase)
preprocessing	...changes of measured orders	order resynthesis (replace level and phase)
	...time signals	source signals of TPA or input for data preparation
	...transfer characteristics	apply predicted changes to measured FRFs or use simulated transfer functions

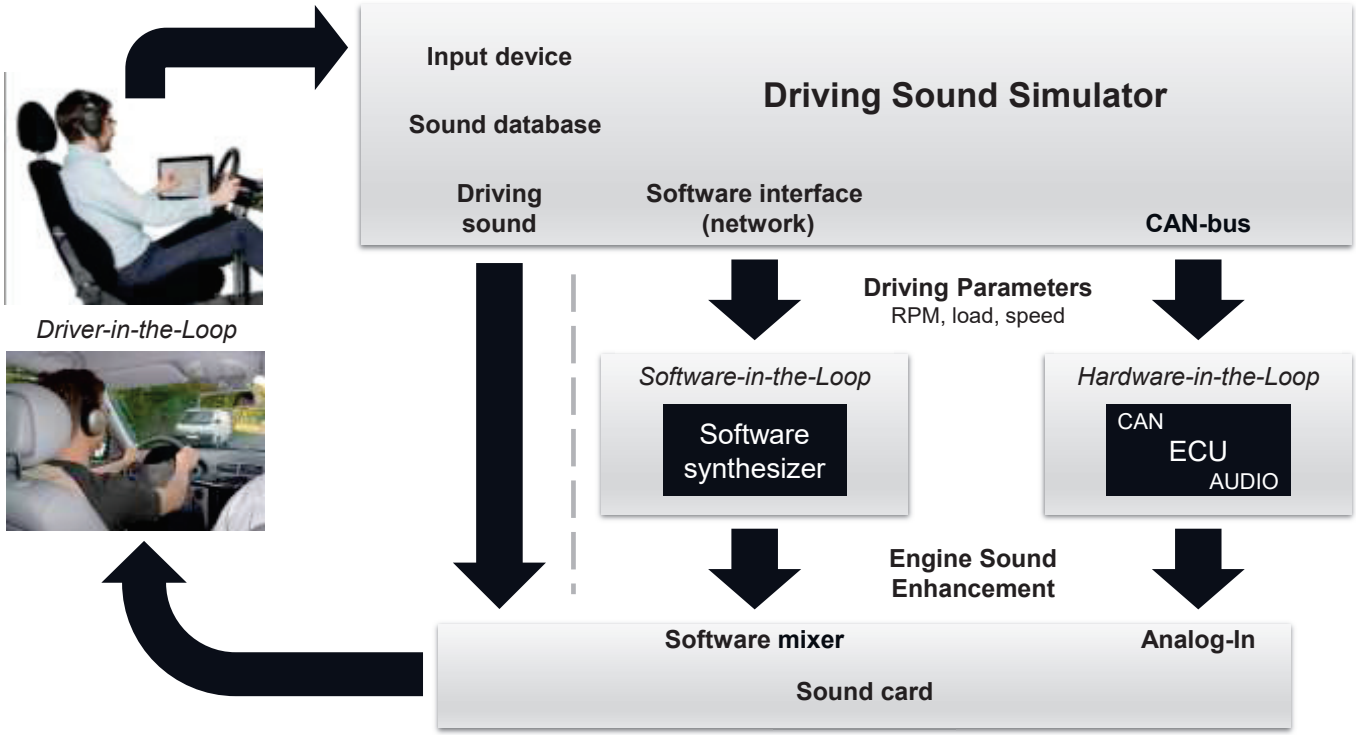

Figure 3: Software-in-the-loop and hardware-in-the-loop for the tuning of Engine Sound Enhancement systems

Engine Sound Enhancement

Artificial engine sounds are played back in electric and hybrid vehicles using cabin loudspeakers to set emotions or give acoustic feedback. It is also used for downsized combustion engines to make the sound more powerful or to mask cylinder deactivation.

In a software-in-the-loop or hardware-in-the-loop approach the sound generating device can already be tuned in the simulator considering the masking noise by wind and tire-road noise (Figure 3).

If the artificial engine sound would be tuned without the masking noise at the desktop the validation in the car will probably fail because the sound could be too loud or too quiet at several rpm. The proposed approach speeds up the process because the masking noise is considered and the real car is only needed for the final tuning.

Control strategy tuning

When all necessary data for a driving sound simulator is available in the desired quality it could be too late for big design changes of the hardware. However, software can be exchanged until shortly before production starts.

A driving sound simulator is particularly suitable for the evaluation of complex systems that involve a lot of human interaction. One example is the energy management system of a hybrid vehicle. The control strategy when it switches from the electric to the combustion engine depends on driving behavior, state of charge, temperature, drive mode and other

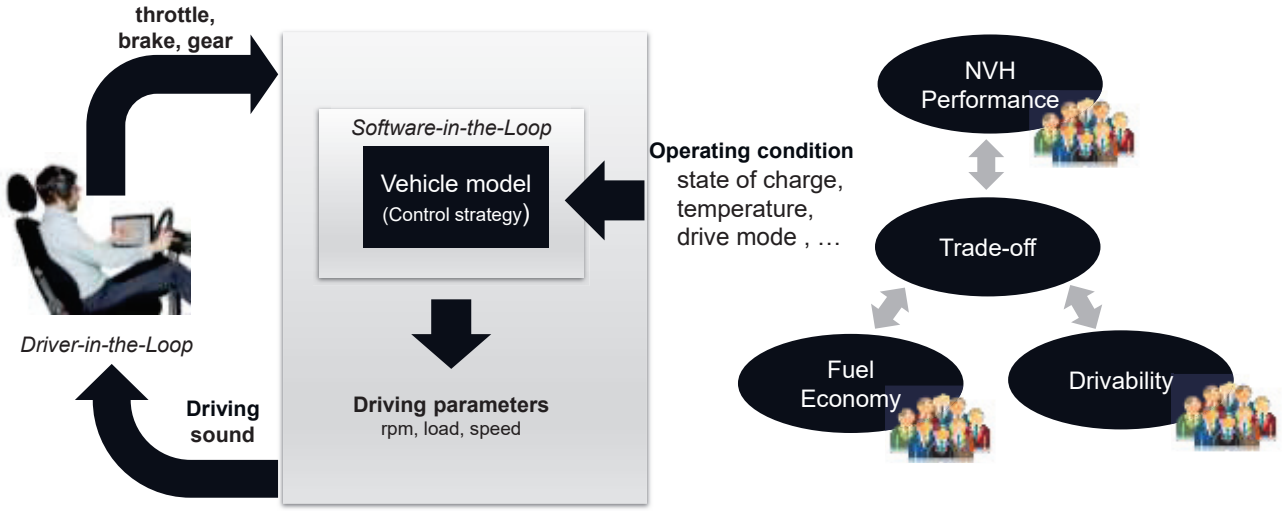

Figure 4: Engineers of different departments can experience the control strategy of a hybrid vehicle in a driving sound simulator.

variables. It affects not only the acoustic performance but also affects drivability and fuel consumption.

In a simulator engineers from all departments involved can tune the energy management system to find the best compromise for acoustics, drivability and fuel consumption (Figure 4).

Another example is a continuously variable transmission (CVT). The rpm and therewith the engine sound is not in a fixed relation to speed but variable. Different strategies can be compared in a simulator.

Decision-making support

A driving sound simulator enables things which are impossible in the real word. The sound can be virtually modified to make what-if-scenarios audible because listening is more meaningful than looking at diagrams. What if we reduce the wind noise by 6dB above 2 kHz? What if we reduce the whining noise caused by the gearbox? Is -6dB enough, should it -10dB or even more? Is it worth to spend more money on a better gearbox mount?

The key is that with interactive filters during the simulation the driver hears immediately the effect of a virtual modification and he can give direct feedback.

Important for the decision-making process is that it is easier to convince colleagues or management if they hear the difference. It explains the effect of a countermeasure more impressively to non NVH-experts without building another prototype.

Sound Design

Based on the current vehicle model the sound designer creates several variants by manipulating engine orders or adding new engine orders (Figure 5). Order tracking filters with variable amplification vs. RPM and signal generators (e.g. order level and phase from simulation) are used.

In a customer study the participants can drive all sounds and select their favorite to define the target sound.

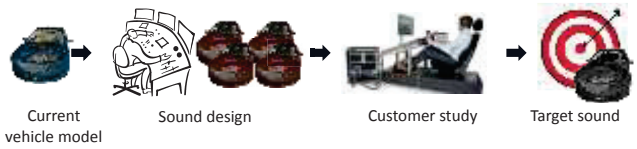

Figure 5: Target sound setting in a driving sound simulator

Sound of the future

Another aspect is evaluating the sound of the future (Figure 6). Are passengers more sensitive to noise while they relax during automated driving? How sensitive are they to unknown strange noise caused by auxiliary components if they are not in control? Such studies could be performed in a driving sound simulator. A full vehicle simulator with motion platform and 360-degree screen would create a high immersion which would be necessary for studies with naïve test persons.

Figure 6: Are passengers more sensitive to noise while they relax during automated driving?

Summary

A driving sound simulator speeds up the development process. A proper evaluation of the sound and driving experience is possible without building an expensive prototype. Key factors are binaural technology, synthesis algorithms for realistic sounds, calibrated multi modal playback, interactive sound design tools and interfaces for software- and hardware-in-the-loop.

In the data preparation Binaural Transfer Path Analysis combines simulated and measured NVH data. CAE data can be used to experience a virtual prototype in the driving sound simulator.

References

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