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Comprehensive Automotive Active Sound Design part 2: Operational Sounds and Brand Sound

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ABSTRACT
The basic approach for comprehensive Active Sound Design has been introduced in (1). In addition to the sound generation for electric and combustion vehicles discussed there, hybrid vehicles require specific treatment: on the one hand the transition between electric and combustion drive modes has to be harmonized, on the other hand the characteristics of the different modes have to be maintained. This is achieved by a combination of the signature-based approach and the order-based approach.
Besides engine sounds the global approach proposed here also generates and supports operational sounds: it synthesizes feedback sounds aligned to the actual vehicle parameters, thereby optimizing the Sound Quality process in terms of time and costs.
The harmonization of all vehicle sounds in combination with the sound signature approach allows the realization of a Brand Sound. Starting from verbal brand descriptors this specific approach transports the Brand Identity into each vehicle. Since such a comprehensive approach has to be implemented into the vehicles specific attention has to be paid to the possibilities of the vehicle adaptations.

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1.INTRODUCTION
The basic approach to perform a comprehensive Active Sound Design for automotive applications has been presented in (1). Besides the applications which are shown there, i.e. sound synthesis for electric and fuel cell vehicles and support of combustion engine sound, Active Sound Design offers a variety of further advanced possibilities. These range from the sound generation for hybrid vehicles over the optimization of operational sounds to the implementation of a Brand Identity into the vehicle fleet.
A feasible adaptation of the resulting comprehensive Sound Design to the vehicles requires a fast and effective approach for editing the sounds. The corresponding topics are discussed and the implementation into the system elvis³ is presented.

2.CENTRALIZED COMPREHENSIVE ACTIVE SOUND DESIGN
Besides the aspects of sound synthesis for electric and fuel cell vehicles and the support of the sound of combustion engines which have been described in (1) additional aspects are needed for a comprehensive Active Sound Design approach.

2.1Hybrid Vehicles
For hybrid vehicles viable approaches for a stringent implementation are not available on the market today. The challenge is the combination of the electric and the combustion driving modes while considering the specific boundary conditions and representing the specific driving modes.
Especially the transition between electric and the combustion driving modes has to be designed and smoothened, while maintaining or introducing a clear audible difference in character into the respective modes. The driver should get a clear feedback as to which mode he is driving in, so that the sound character allows a clear differentiation. On the other hand the electric and combustion mode need to have enough similarities to be associated with the same vehicle and to represent the brand.
This task is a typical application for the signature based approach as has been implemented in elvis³ E-motion. The sound signatures can be used to define the character foundation, while the actual vehicle parameters adapt the sound to the dynamic behavior.
A further challenge of hybrid vehicle sound is the Continuously Variable Transmission (CVT) which most of these vehicles use. One of the most important and well-known dynamic sound coupling aspects of any vehicle is the relation between engine rpm and speed which is broken up by this transmission system. The sound of the engine does not fit to the dynamic behavior of the vehicle any more, resulting in irritations of the driver. The sound design has to put specific attention

to this effect, either by trying to re-establish the relation if the engine sound itself is not dominant, or by embedding the existing engine sound in a clever way.

Figure 1 shows the spectrograms of the sound of a hybrid vehicle in electric and combustion driving modes. The missing relation between the sound and the vehicles dynamic behavior, i.e., speed, becomes obvious.

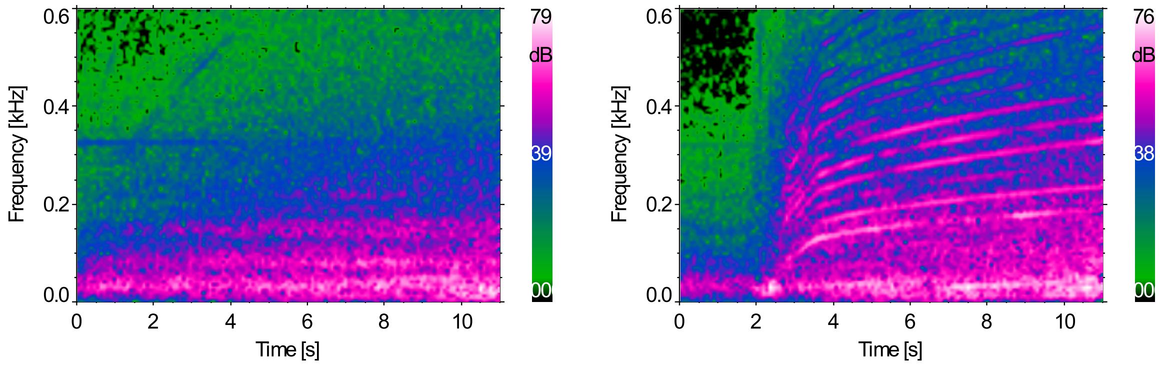

Figure 1 – spectrograms of a hybrid vehicle with CVT gear system in electric driving mode (left) and combustion driving mode

Regarding the most feasible methods, hybrid vehicles thus require hybrid sound generation. This can be realized by combining the methods for electric vehicle sound generation with combustion engine support to connect and harmonize the two driving modes, as has been done in the combination of elvis[3] E-motion and Cesar

2.2Operational and Feedback Sounds

In recent years, major efforts have been undertaken to raise the level of overall comfort in vehicles. One of the results is that today's vehicles show a significantly lower interior sound level compared to previous model generations. As a side-effect, masking which had been caused by the biggest noise sources has been reduced. Each single component therefore has to be optimized with regards to the emitted sound, and a harmonization of the overall sound can hardly be realized. In addition, the current feedback sounds are mostly static and somehow unnatural and in most cases not particularly appealing.

Active Sound Design methods can be time- and cost-effectively used in this context as well to optimize the Sound Quality, to tune the sounds to each other and to harmonize the overall sound.

First, not only engine sounds can be synthesized or supported by active methods, but also operational sounds. In principle the sound of an electric motor of a vehicle component can be optimized with the same methods used for the optimization of the sound of an electric vehicle. Tonal components caused by the motors can be embedded in different harmonic sound structures, slight roughness originating from gear systems masked by broadband components, and modulations caused by non-uniform excitation or forces distracted by overlaid sound structures.

Sound optimization by Active Sound Design reduces the required degree of work using conventional methods. This can save costs, reduce the components' weight, and lead to a shorter development cycle. Another huge advantage is that the final optimization can be performed on total vehicle level, that is, when all components are fully developed and the final vehicle is available for assessment. At this point the final overall vehicle sound is available, and it is usually far too late to change the components itself. Active Sound Design Methods can thus relieve a huge portion of stress from the entire development cycle.

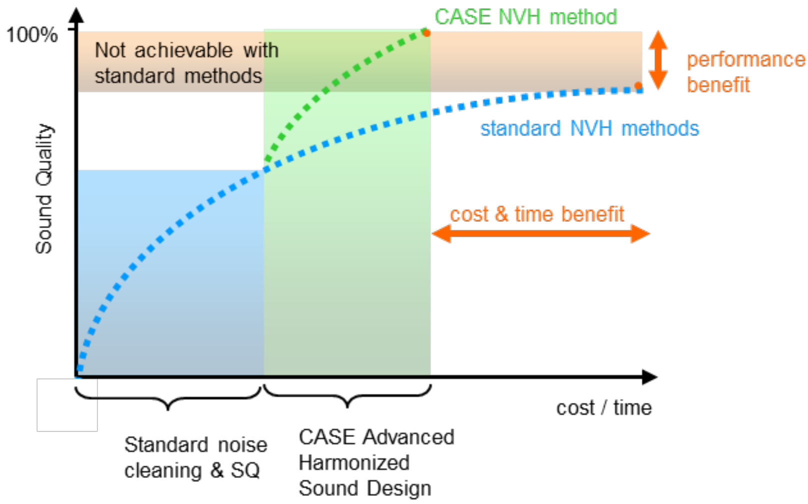

Figure 2 – cost function of the optimization of operational sounds using conventional and Active Sound Design methods

Feedback sounds are mostly fixed sounds which are played back at defined events, e.g., the turn signal, a light warning or the seatbelt reminder signals. The turn signal mostly replaces the sound of the relay which had been used in former times, but the remarks given on combustion sound support in (1) hold true. The sounds produced by an alternating mechanical relay are never completely identical, while they are for the simulated relay sound being played back. The original sound shows minimal variations in level, duration, alternation frequency, while the synthetic one is fully static. This can easily be avoided by synthesizing or manipulating the feedback sounds, where the sound can be influenced for example by vehicle parameters and where variations can be introduced into the sound generating or manipulating parameters. The resulting sound is perceived as being more natural, representing a personality, and giving some emotional value to the vehicle.

Further sound effects can be created which increase the perceived naturalness and support emotional feedback. An example is the synthesis of backfires, an effect which some sports cars use to make the sound more attractive and powerful. Originally, older vehicles created small explosions of non-combusted fuel in the exhaust system because of “misfirings” of the engine. Nowadays, the backfires are deliberately tuned into the engine calibrations resulting in controlled firing of fuel in the exhaust. This is rather complicated to implement, especially for fast automatic gear switching systems, wastes fuel and also has a negative impact on the catalytic converter. The life-like synthesis of backfiring sounds thus shows a number of advantages.

The above mentioned features are integrated into the module elvis[3] CASE.

2.3Brand Identity and Harmonization

Optimizing each single component does not necessarily optimize the overall vehicle sound. Instead the optimization of the combination of the different sounds does the trick. The different components form different instruments in an orchestra, and the “composer” has to shape and arrange them to form a appealing and satisfying overall sound. Furthermore, the shaping can be performed so that the sound exemplifies attributes which are typical for a vehicle’s brand, thus realizing a Brand Sound.

The modules of Active Sound Design described above constitute the tools for a corresponding implementation. In order to achieve this a holistic process has to be devised. Based on the Brand Attributes describing the core identity of the brand, a rule-based process is used to break this down into sounds used in the vehicles. The rules define the generic bonding of sound attributes to Brand Attributes. This allows for the creation of a variety of sounds representing the Brand but showing substantial individual deviation. Hierarchically conceived Active Sound Design schemes are used to generate, support, and modify all vehicle sounds. All individual sounds are driven by the globally defined rules. Following this approach, the segmentation into vehicle classes, the refinement of the Brand characteristics, and the evolutionary development of the sounds becomes easily viable.

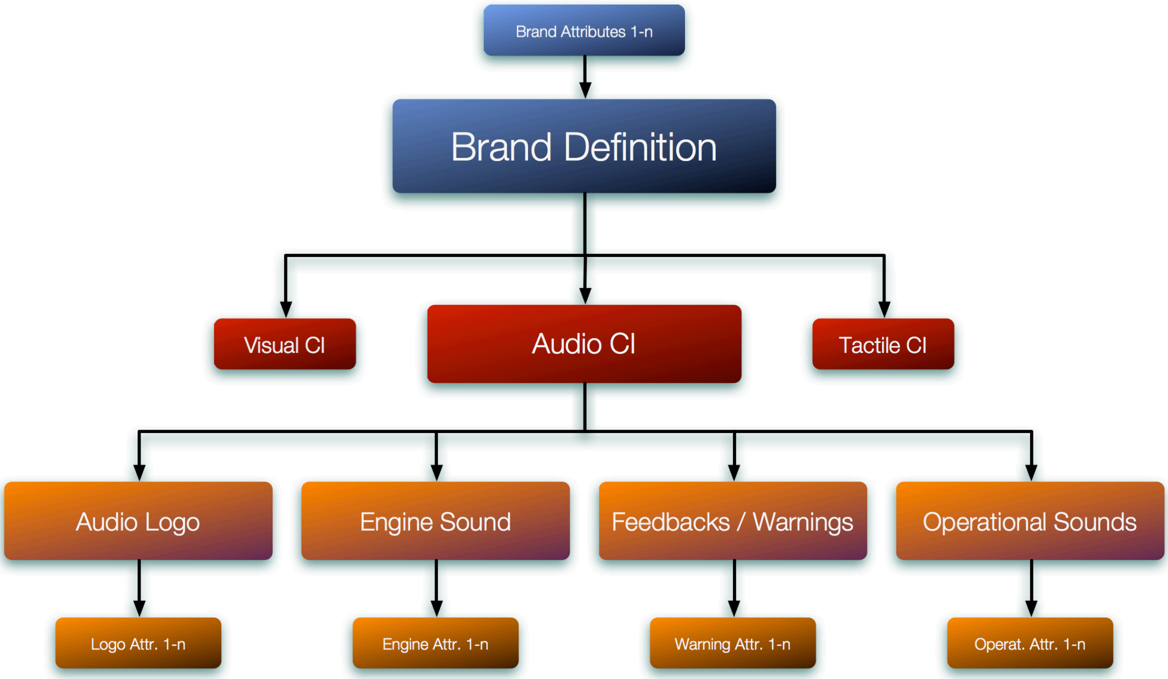

Figure 3 – Brand Sound implementation scheme

3. VEHICLE IMPLEMENTATION AND ADAPTATION

The application of the methods into the vehicles requires a centrally controlled Active Sound Design process. In actual vehicle implementations (e.g., in the AMG SLS Coupé Electric Drive) this has been realized by a dedicated hardware device. It communicates with the vehicle via a CAN bus interface and feeds the generated sound into the vehicle's default audio system.

A leaner approach is to implement the algorithms directly onto the vehicles head unit. This offers the advantage to control all audio aspects from one point while saving an additional hardware unit. Several implementations of this approach are currently under way and will hit mass market production in the next months.

The most important aspect of aligning sounds to vehicles is that all sounds have to merge fully into the dynamic behavior of the driving vehicle. Thus only basic adaptation work can be performed in laboratory condition, e.g., in a simulation environment. The fine-tuning has to be performed directly in the driving vehicle. For this direct access to all sound generation parameters during driving is required. In the elvis[3] system this is solved by a direct-to-unit editor. It enables the user can control the target hardware/software of the vehicle implementation in real-time while driving. In combination with the perception-driven approach the adaptation effort is significantly reduced and the development cycle dramatically shortened.

4. SUMMARY

Active Sound Design allows a comprehensive forming of vehicle sounds. To do so, a centralized approach is proposed that tackles the different Sound Design tasks by a modular implementation, edible in real-time.

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