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Proposal of a Score-based Sound Design Method for Electric Vehicles -

Norio Kubo [1)]

1) EV Soundscape Limited

1-13-2 Ishikawacho, Naka-ku, Yokohama, Kanagawa 231-0868, Japan (E-mail: info@evsoundscape.jp)

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Electric vehicles (EVs) are inherently quiet, and this characteristic creates new challenges for both exterior and interior sound design. In conventional internal combustion engine vehicles, many acoustic cues related to acceleration, vehicle presence, and emotional character are naturally generated by the powertrain. In EVs, however, such cues must be intentionally designed. This paper proposes a score-based sound design method that describes EV sounds in terms of temporal structure, frequency transition, intensity, and event timing, analogously to a musical score. The aim is to provide a practical design language that can integrate safety, functionality, and emotional value in EV sound creation.

One of the central issues in EV sound design is the trade-off between warning effectiveness and brand representation, especially in acoustic vehicle alerting systems (AVAS). Sounds with strong warning character may become unpleasant or intimidating, while attractive brand-oriented sounds may reduce detectability. The proposed framework addresses this contradiction by assigning different perceptual roles to different time phases. In AVAS, for example, the approaching phase emphasizes detectability, the near-field phase conveys brand character, and the passing phase is designed to fade without leaving an excessive impression. This temporal allocation of functions is one of the main ideas of the score-based structure method.

The paper also points out that EV sounds differ fundamentally from those of internal combustion vehicles. Engine vehicles can be interpreted in a pipe-instrument-like manner because their sound is dominated by combustion pulsation and rotational orders. EV sounds, in contrast, are more appropriately understood in a string-instrument-like manner, where continuous tones, harmonic structures, structural vibration, and speaker-based augmentation are combined. Therefore, not only timbre but also “when and how the sound changes” becomes a major design variable.

To implement this concept, the study introduces three signal-processing operations called EVSP I–III. EVSP I controls flow, propulsion feeling, and energy by compressing or stretching time signals. EVSP II adjusts time gaps between pulses or sound events to influence urgency, attention, and approach perception. EVSP III adds event-driven sounds corresponding to vehicle state changes such as start-up, threshold speed, or transition events. By combining these three operations, designers can create meanings and impressions that cannot be expressed by timbre alone.

For interior sound design using active sound design (ASD), the paper proposes a three-phase structure consisting of expectation, development, and transition. The expectation phase introduces the onset of resonance or a fundamental tone to suggest that something is about to happen. The development phase reinforces continuous acceleration by adding harmonics and shifting spectral emphasis. The transition phase inserts short event sounds that correspond to changes in driving state. This approach makes it possible to create sportiness and emotional uplift without relying simply on higher sound pressure levels.

For exterior sound design, especially AVAS, the framework considers several pedestrian interaction scenarios, such as encounters with a single pedestrian, crowded urban situations, and quiet residential areas. The required balance between warning, comfort, and brand expression changes depending on the scene. The paper therefore suggests that future systems may adapt sound structure dynamically according to road conditions and surrounding environments, potentially with AI-supported scene recognition.

In addition, the paper discusses the relationship between sound design and AI-based sound quality evaluation, named AI-SQ Engineering. This framework combines psychoacoustic parameters with multiple AI approaches, including clustering, spectrogram-based pattern recognition, and listening-model construction. The key idea is not to replace human judgment, but to use AI to identify important phases and parameters in the score-based structure. In this way, conventional one-dimensional sound quality evaluation can be reinterpreted as a two-dimensional design problem involving both parameter space and time structure. The paper refers to this bridge between evaluation and design as creative sound design.

In conclusion, the proposed score-based sound design method offers a new engineering framework for EV sound development. By treating EV sounds as structured temporal phenomena and linking them with AI-assisted evaluation, the method provides a way to integrate warning performance, brand identity, and emotional value. It also opens the possibility of future database-driven and human-in-the-loop sound design systems for next-generation electric vehicles.

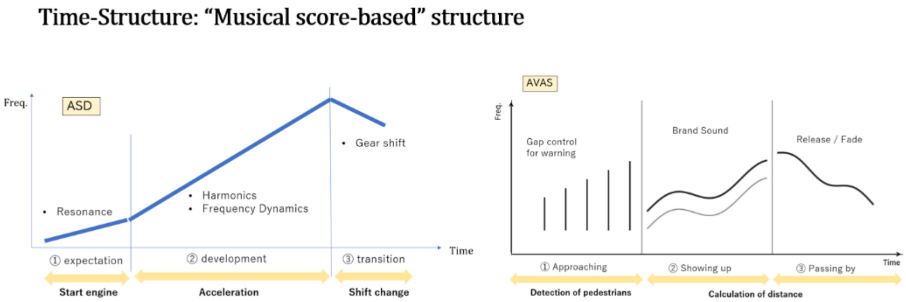

Fig.1 “Score-based” structure for ASD/ AVAS