Evolutionary algorithms for the engine sound specification of electrical vehicles

Jörg Bräuer[1], Stefan Twieg[2], Matthias Rötting[1]
[1] Institut für Psychologie und Arbeitswissenschaften, 10587 Berlin, E-Mail: joerg.braeuer@tu-berlin.de
[2] Volkswagen AG, Konzernforschung, Fahrzeugtechnik/Akustik, 38436 Wolfsburg,
E-Mail: stefan.twieg@volkswagen.de

1. Motivation

With an increasing number of electrical vehicles, problems arise regarding the acoustic comfort. Due to missing masking effects by the sound of the engine, wind noise, tire noise and auxiliary components become audible and may lead to annoyance.

Additionally, studies revealed that the missing engine noise also results in a lack of driver feedback which may cause a false estimation of the actual driving condition, i.e. underestimation of the current velocity [1].

Therefore an active influence on the interior sound is desired to provide an intuitional driver feedback and mask driving noise at the same time. However, as the electric drive train acoustically as well as technically differs strongly from drive trains based on combustion, the user acceptance is doubtful if these technologies were connected by using typical combustion engine sounds in electrical vehicles. Yet, it is not clear what these cars should sound like.

Since the sound of electrical engines is based on the speed it seems reasonable to create artificial sounds by applying the principle of engine orders. As this application allows for a wide variety of complex sounds in an unknown solution space and as manual sound creation is tedious, it is furthermore desirable to automatically create sounds by specifying abstract terms, e.g. sporty or pleasant.

2. The evolutionary algorithm

The method of evolutionary algorithms as a stochastic tool for finding good solutions within unknown solution space seems reasonable to account for the motivated goals of artificial driving sounds. Moreover the use of the principle of engine orders appeals due to the fact that each engine order (*EO*) can easily be represented by a small number of fixed points as can be seen in figure 1.

The figure shows the general composition of all individual sounds that can exist within the algorithm. Each individual features the same number of chromosomes, with each chromosome representing one engine order sine wave. The chromosome consists of the engine order number EO_k, the amplitude of the order A_k and the corresponding speed n_k. The relationship between n_k and A_k is given by the row index. The sound of the engine order S_{EO} is created by interpolating the sine value at any given rpm n.

$$S_{\mathrm{EO}\_k}(i) = A_{\mathrm{interp}}(A_k, n_k) \cdot \sin\left(\frac{EO_k \cdot 2 \cdot \pi \cdot n}{60} \cdot t\right) \tag{1}$$

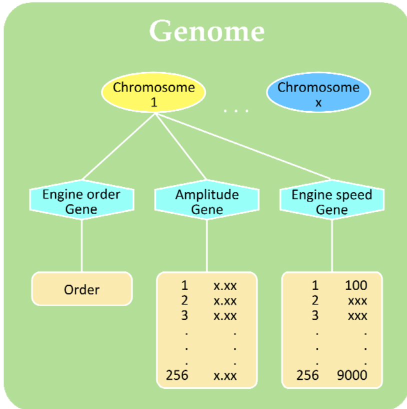

Figure 1: Example of a possible genome of the algorithm. All individual sounds share these basic traits of character.

The complete driving sound S defined by an individual can be created by merging the information of all k chromosomes.

$$S = \sum_{k=1}^{x} S_{\mathrm{EO}\_k} + \mathrm{Reference} \tag{2}$$

The algorithm creates a specified number of individuals with completely random chromosome entries that form a basic population. The chromosomes of these individuals are then recombined and mutated to form new, mixed individuals.

After the composition of the sounds of all available individuals, each sound is filtered according to preceding transfer path analysis to emulate the head related transfer function of each seat. The addition of an original recording of the car interior conducted with dummy head microphones at all seats that are to be taken into account allows for the simulation of the new interior sound condition.

These sound conditions are evaluated mainly using psychoacoustic parameters and compared to the original acoustic condition of the car. As a result, each individual is given a numeric fitness value which determines its chance to stay within the population when a random selection reduces the population.

All individuals left within the population then form a new generation and the whole evolutionary process of recombination, mutation, evaluation and selection is repeated until an abort-criterion is met. This criterion could be e.g. a specific fitness value is reached or a fixed number of evolutionary steps has completed.

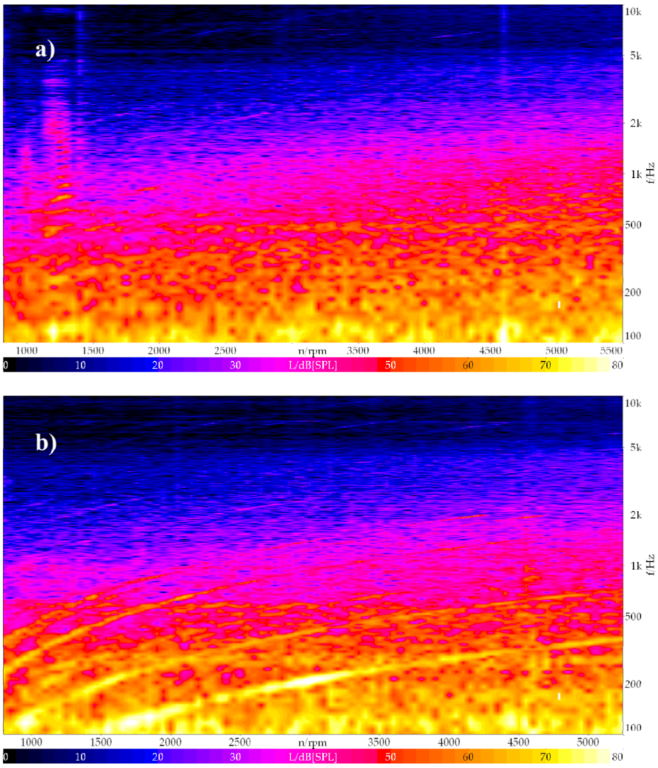

Figure 2: Diagrams of the original sound of an electrical vehicle at WOT-acceleration to 80 km/h (a) and the evolved artificial sound created by the algorithm.

3. First algorithm results

The figures 2a and 2b show the diagram of a full throttle acceleration of an electrical vehicle to the velocity of 80 km/h. While figure 2a shows the original sound condition, figure 2b shows an example of an evolved sound based on psychoacoustic characteristics like sensory pleasantness [2] or psychoacoustic annoyance [3].

Although the original population consisted of totally random individuals and amplitudes, the algorithm created a sound with only a small number of different characteristic engine orders to maximize the individual fitness according to the fitness function.

Also masking effects are taken into account by the addition of rather low engine orders to overshadow the road noise of the original signal. Additionally these engine orders only feature large amplitudes as long as their frequency corresponds to the frequency domain of the road noise. As the distance between road noise and engine order expands, the magnitude of the amplitude decreases to avoid the subjective impression of annoying sharpness.

4. Summary and future prospects

So far, the algorithm provides reasonable artificial sounds that follow specific engine orders and feature enhanced psychoacoustic characteristics.

However, at this early stage the algorithm can only be seen as a tool to provide sounds with distinct psychoacoustic traits. The application of psychoacoustic characteristics seems promising. Compared to the description of a sound only considering the physical values of sound pressure level and frequency, it allows for a more sophisticated description. The advantage of using psychoacoustic parameters is the consideration of the impression of artificial sounds on the human hearing.

These distinct psychoacoustic sound characteristics can be used to examine a possible connection between psychoacoustics and abstract terms like sporty or luxurious. If that connection can be established, it will be fast and easy to produce individual car sounds according to e.g. a customer's taste.

References

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