Perceptive Qualification of Engine Sound Character

Validation of auditory attributes using analysis synthesis method

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Introduction

For over 2 years PSA Peugeot Citroën has been studying sound identity of 4-cylinders gasoline vehicles. Using free sorting experiences we observed that the sound of vehicles in dynamic situations can be sorted in 4 main categories. One category for which sound identity is important in consumer's choice is the so-called "sporty class". We first identified salient perceptual attributes for sport character. Then to improve our understanding of the links between signal and perceptual attributes, we developed HARTIS, a resynthesis software based on IRCAM's jMax programming environment. HARTIS allows us to generate perfectly realistic car sound with modifications of engine harmonics and noise. Using HARTIS, we prepared 2 experiments presented here : evaluation of sport character and influence of timbre change on perceived engine acceleration. The results of those experiments highlight the fact that roughness [1], booming and timbre change (s?) are salient auditory attributes of sport character. We also emphasized 2 different representations of sport character. Moreover, we observed that simple signal modifications can highly influence perception of engine acceleration.

General approach

How to give a vehicle the voice corresponding to it's personality, and moreover to it's driver's personality ? To answer this question, we use a cyclic approach leading from customer preferences to engineering solutions via perceptual approach and acoustic signal processing (figure 1).

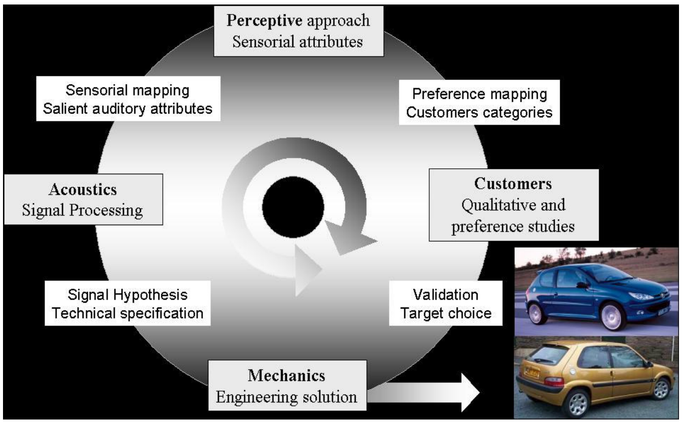

Figure 1: General process for the sound design of a great sports (or "powerful"…) car.

In this paper we will focus on the steps "Signal processing" and "Perceptive approach". The link with customer's preferences and engineering solutions will be discussed in later papers.

Sound classes and auditory attributes

Using a free sorting experiment, we identified 4 main sound classes and 6 subclasses of interior car sounds. The experiment was made on a set of 21 2 seconds samples recorded inside vehicles in a 3rd gear full load acceleration situation (3FL). 50 naïve subjects participated in this experiment. After the sorting task, subjects were asked to describe the sound groups they formed, in order for us to understand their classification. An overview of the perceptual mapping obtained by Correspondence Analysis (CA) is given on figure 2.

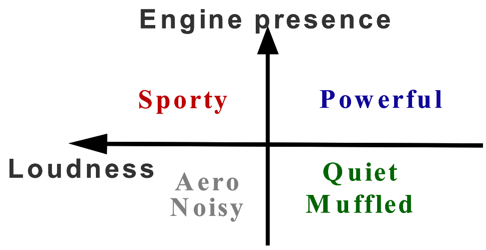

Figure 2 : Overview of the perceptive mapping obtained by CA with the free sorting experiment, and main identified signal attributes (Loudness and engine presence) .

Expert listening sessions, semantics analysis and a first signal processing study highlighted the fact that the perceptual mapping on figure 2 can be explained by 2 main parameters : loudness [2] and engine presence. Moreover, we observed that sporty sounds are characterized by booming sensation, roughness sensation and a timbre variation "ON" to "AN". We will now see how to improve the link between those perceptual attributes and signal parameters taking into account technical vehicle constraints.

Sound synthesis and signal parameters

Using IRCAM's jMax programming environment, we developed a software called HARTIS (HArmonics Real TIme Synthesis) to resynthesize realistic car sounds from measurements made with an artificial head (later paper). Taking into account technical feasibility of signal modifications, HARTIS allowed us to identify signal parameters corresponding to the perceptual attributes emphasized above. Thus we observed that salient perceptual attributes could be linked to technically controllable signal criteria : Booming sensation is linked with level of 2nd and 4th engine orders (H2 and H4). Roughness sensation is linked with level of H3.5 to H4.5 (for "ROU" sounding roughness), or with level of H9 to H12 (for "GRR" sounding roughness) [3]. Timbre variation is linked with level variation of H2, H4 and H6; sensory analysis showed analogy between booming and nasal phoneme "ON" and "AN". Using a very simple formantic model of booming, we assumed that the first formant frequency F0 is directly related to H2, and the second formant frequency is related to the Spectral Centre of Gravity (SCG) of H2, H4 and H6. Thus the more H4 and H6 levels increase, the more engine timbre changes. Assuming those links, we organized 2 experiments in order to study the influence of perceptual attributes on perception of sport character, and relationship between signal and perceptual attributes.

Perceptual tests

Evaluation of sport character

Procedure

56 naïve subjects participated in this experiment. The sound set was composed of 20 samples generated with HARTIS from a unique “quiet” car sound. All sounds were 4 seconds 3FL accelerations from 3500RPM to 4500RPM. Samples were modified on 4 parameters : booming sensation (H2 level), timbre variation “ON” to “AN” (H4 and H6 level variation), slow roughness “ROU” (H3.5 to H4.5 level), and fast roughness “GRR” (H9 to 15 level). Subjects were asked to evaluate the sport character on a linear scale from “not sport” to “very sport”.

Results

A Principal Component Analysis (PCA) gave the results on figure 3 : sound discrimination is made on the booming / “ON” to “AN” sensation and on the fast “GRR” roughness.

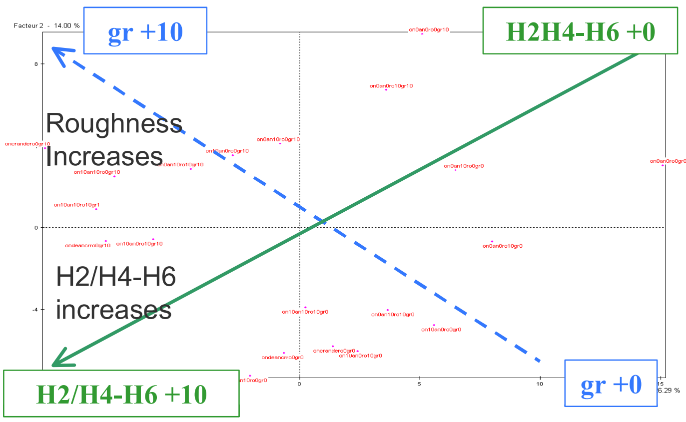

Figure 3: PCA on sport character evaluation. Main discriminative attributes are booming/timbre variation (green arrow) and fast “GRR” roughness (blue arrow).

Using Cluster Analysis, we emphasized 3 subjects classes including a non significant 1st class (random evaluations), a 2nd class focused on booming and “ON->AN” sensation, and a 3rd class focused on the fast roughness sensation. For the 2nd class, it appears that booming is a salient sport attribute and that sport character is increased by the timbre variation.

Conclusion : sport character

2 sport characters are identified : booming / “ON->AN” sport, with high pair engine orders levels, and rough sport with high H9 to H15 levels.

Timbre changes and perception of engine speed

Procedure

We used HARTIS 3FL sounds with equalised engine speed slopes (3500 to 4900 RPM) and duration (4 seconds), to study the influence of signal parameters on the perception of engine acceleration. 38 naïve subjects participated in this experiment. We used 3 sound sets composed of 7 sounds each. Set 1 is composed by 7 sounds from a unique “powerful” car; set 2 is composed by seven sounds from a unique “noisy” car, and set 3 is composed by sounds from 7 different cars. For each set, the sounds are presented by pair (21 pairs per set), and the task is to “choose the sound that have the fastest rise of engine speed”. For sets 1 and 2, signal is modified on 3 parameters : H2 level; all engine harmonics less H2 levels (engine presence); and H6 to H10 pair and impair harmonics levels.

Results

We studied correlations between signal parameters and subjective engine acceleration ratings. For set 1, subjective engine acceleration rating is highly correlated with a linear combination of Harmonic/Noise Ratio (HNR) and Spectral Centre of gravity (SCG) with the determination coefficient $R^2 = 0.96$. For set 2, the results are highly correlated with loudness ($R^2 = 0.96$). For set 3, the results are strongly correlated with a linear combination of HNR and Harmonics SCG ($R^2 = 0.99$). Temporal aspects : we studied the variation of coefficient R^2 with the temporal position for calculation of SCG and loudness. For sets 1 and 2, we highlighted that the correlations are higher considering only the last second of signal. For set 3, there is no influence of the temporal position for calculation of HNR and SCG.

Conclusion : engine acceleration

For “noisy” car sounds (set 2), engine sound characteristics does not contribute to perceived engine acceleration. The influence of engine sound is salient by its contribution to global loudness. Loudness in last second of signal is a factor of perceived vehicle speed, more than a factor of perceived engine acceleration. For “powerful” homogenous car sounds (set 1), HNR and SCG explain perceived engine acceleration : the more present engine harmonics are, and the higher perceived pitch is, the fastest engine seems to accelerate. Last second of signal is salient for ear’s judgement. For set 3 (mixed sounds), HNR and <u>harmonics</u> SCG on the <u>whole signal</u> are salient parameters for perceived engine acceleration. Harmonics SCG is more relevant than global signal SCG because “noisy part” of signal is different from one sound to another, and ear focalizes on engine information contained in the harmonic part.

References

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