Man-Machine Interfaces in Cars: Technological Impact of Sound Design

Sabine Langlois, Bénédicte Le Nindre, Claire Peteul,
Renault, Research Department, 1 Avenue du Golf, 78288 Guyancourt Cedex, {sabine.langlois, benedicte.le-nindre, claire.peteul}@renault.com
Nicolas Misdariis,
Ircam, Sound Design team, nicolas.misdariis@ircam.fr

Apart from the radio, the sound environment inside a car consists of the mechanical noises of the running car and the electronic sounds added to help the driver. We focus here on the turn signal.

We conducted a listening test with sounds of actual cars and found out that customers do not all share the same opinion. If all customers agree on basic sound characteristics (rhythm) related to the function of turn signal, some appreciate actual sound quality (timbre) whereas the others expect more creative sounds.

Then, our guideline was to design sounds that work well with different car environments (materials,…). Modalys, a sound synthesis tool developed at IRCAM, suited our needs. Therefore, IRCAM/Sound Design team to formulate the problem in terms of methodology and to create sounds for us.

The next step was to install the sounds in cars.
In Renault cars, the turn signal sound comes from the dashboard. It is very simple (two frequencies) and easy to produce with the technology used (microcontroller and buzzer).
We chose target sounds from the IRCAM database. To convert our wave files to car technology, the electronics engineer and the supplier had to better understand the performances of typical car components. In doing this, they discovered new capabilities. As such, the target sound guided further refinement. The implemented signals have a better sound quality without a major cost effect.

The turn signal is not the only man-machine interface inside a car; other sounds are played. We have to insure the coherence of all such sounds. Future work deals with this task.

1. Introduction

Apart from the radio, the sound environment inside a car consists of the mechanical noises of the running car and the electronic sounds added to help the driver. We focus here on the turn signal.
Whereas the turn signal was made before by a mechanical relay, it is now "played" electronically. This technological change allows us to modify the characteristics of the sound made by the turn signal and so offers the possibility to create sounds never heard before.
We first conducted a listening test to understand which turn signals the customers like and dislike. We thus collected ideas to design new sounds, which is what we did with IRCAM without taking into account the technology used in our cars. The next step was naturally for us (researchers in psychoacoustics) to learn how to transpose these sounds to this technology. The experience had an unexpected side effect: electronic engineers and suppliers discovered some unknown capabilities of the electronic devices.

2. Sound Quality Study

Our first objective was to understand which turn signals the customers like to hear and why. We decided to work on sounds made by actual cars. We realized that many kinds exist, and that turn signals of Asian cars have a specific sonic signature. We thus decided to concentrate on European turn signals, and chose 12 cars representative of the market.
We recorded the sounds inside the cars, engine off, in a semi-anechoic chamber with a Head Acoustics HMS III dummy head. The sounds were played back in a quiet room through a Head Acoustics amplifier and HAII (Sennheiser) headphone; this apparatus ensures that sounds are played back at real levels.
Forty-three persons participated in the listening test. The test consisted of three steps:

1. Free categorization: the subjects were asked to group together the sounds they heard as sharing common characteristics, and to define the representative of each group. They were allowed to form as many groups as they liked, and to put as many sounds in each group as they wished.
2. Description of the group: the subjects were asked to write down how they would describe each group.
3. Projection along the "sound quality" axis: on the test sheet, we drew a line with "0" marked at one hand and "10" at the other end; the subjects were asked to place each representative along this axis.

During the test, the subjects could listen to the sounds as often as they needed.
We often use this type of test for preliminary studies [1]. The theory underlying the categorization step can be found in [3] or [4].

2.1 Results

To analyze the free categorization, we used an algorithm [4] that checks which sounds are most often placed together in the same group, pair by pair. The result can be represented by a tree, whose leaves are the sounds and whose nodes are the consensual groups. The algorithm indicates the quality of the tree, i.e. the degree of agreement between the subjects (here 15%, which is under the 20% upper limit we accept).
We obtained here six groups, each containing between one and three sounds, as shown in Figure 1. Note that we rejected sound 8 from group 6 because it sounded too differently from sounds 7 and 10.

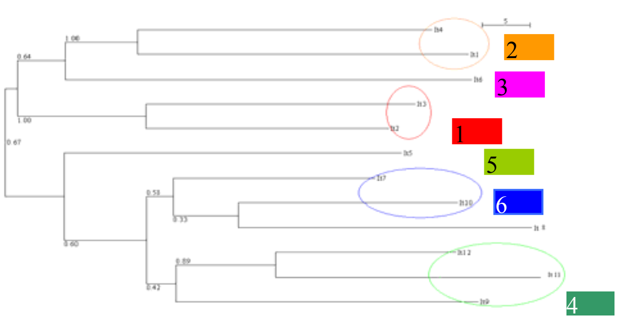

Figure 1. Tree computed from the categorization data

We conducted a semantic analysis of the verbatim to define which subjective criteria the persons used to describe each group. The verbatim dealt with sound description (regularity, speed, level, pitch difference between tick and tock, low / high-pitched, attack, decay, timbre), interpretation of similarity between turn signal and sound sources (material, animal, clock, watch, mechanical / electronic), and judgment (old / modern, pleasant).
The first group of sounds (the most consensual one) is described as "regular, large pitch difference between tick and tock, electronic"; the second as "irregular and slow"; the third as "irregular, quick, low level, no pitch difference between tick and tock); the fourth as "regular, quick attack ("sharp"), like a clock, metallic"; the fifth as "high level, large pitch and decay difference between tick and tock, aggressive"; and the sixth as "low-pitched, large decay difference between tick and tock, like a clock, old".
To analyze the projection along the "sound quality" axis, we used software [5] based on multi-dimensional scaling, that optimizes the distances between sounds to get the most consensual representation, in one or more axes. If we use only one axis, we get a large error (27%), a poor result that indicates that the customers do not share the same preference. The representation along two axis is much better (error is reduced to 17%).
When we go back to the "sound quality" axis of each subject, we observe that nobody uses the full range of the scale: the best mark is only 6/10, which allows us to conclude that the customers are not very satisfied with the actual turn signal sounds.

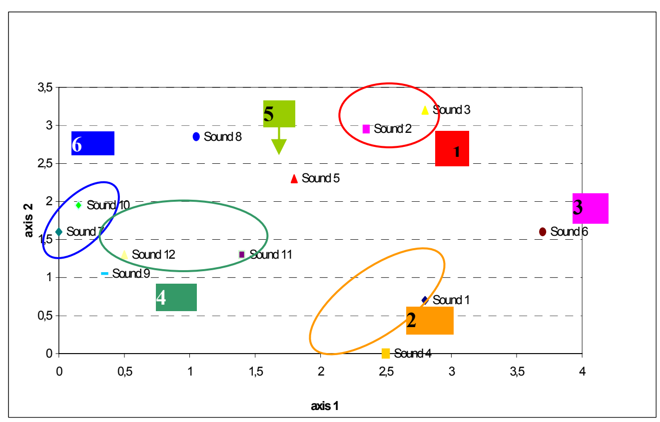

Figure 2. Two-axis preference mapping computed from the "sound quality" projection data

Note that on the preference mapping, the software puts the most appreciated sound at zero. Figure 2 shows that this two-axis representation allows us to find again the categorization groups, which was not possible with one axis. This result guarantees the reliability of the two-axis mapping. In order to understand why people like or dislike sounds, we can thus refer to the verbatim analysis and get the following results:

The first part of the population of customers appreciates regular sounds with high level, even rhythm (duration between tick and tock equal to the one between tock and tick), and large pitch difference between tick and tock. They like turn signals that refer to the mechanical world of clock and watch, i.e. turn signals that sound like the mechanical relay used before.
The second population prefers slow, low-pitched sounds, with low level and quick decay.

2.2 Conclusion

Whereas for the first population, the function of the sound ("my turn signal is on") should be the priority, the second population appreciates that the turn signal becomes part of vehicle comfort, and expects that car manufacturers explore the possibilities offered by electronics to propose turn signals with new tones. Everybody agrees on the fact that actual sounds are not so nice.
This test has also brought to light the evocative power of sounds: some people associated these sounds with clocks, animals and materials. This result offers us a new domain to investigate.

3. Sound Design

We already had the idea that interactions exist between sound and other senses. The associations suggested during the test confirmed that this is an interesting direction for sound design of turn signals. We thus decided to create sounds of turn signals that would be in harmony with the ambience inside the car, and especially with the materials used for seats, door cladding, dashboard... As such, hearing will match with touch and vision. We also wanted to design different sounds for the different cars made by Renault: family, sporty, city or luxury cars, where a specific ambience defines each type of car.

3.1 Method

To create sounds in direct connection with material composition (wood, metal, plastic, tissue…) and touch (knocking, friction…), we decided to work with IRCAM Sound design team and the sound synthesis tool Modalys, developed at IRCAM for about fifteen years. This tool is a sound synthesis engine based on a physical modeling that gives access to a quite large collection of elementary physical structures, either mechanical (string, plate, …) or acoustical (closed-open tube, …) and a series of physical interaction (hit, plucked, bowed, blown or even glued, …). Besides, thanks to its modular property, one can combines elementary models as mentioned above to create a complex structure.For instance, a musical instrument model, or any other "super-structure" that could be, of course, much more unrealistic than the former. The sound computed by Modalys is then the vibrating data of one or several points of the model, as if one would put a contact microphone on the surface of the given structure (see [6]).
In order to create turn signal sounds, IRCAM Sound Design team explored different types of structures, with different mechanical parameters (density, Young's modulus …), excited in different ways, and got thirty different sounds. On the one hand, the sound quality study and further objective analysis (not presented in this paper) have shown that there are fondamental properties that the sound has to respect in order to fulfill its function of information. These properties are regularity (duration between two ticks perfectly constant), even rhythm (duration between tick and tock equal to the one between tock and tick), speed and overall level. Note that we also took into account the bandwidth of frequency response of the buzzer (roughly between 1 and 5kHz). On the other hand, these studies have brought to light other directions as yet unexplored, in particular timbre, pitch, attack and decay, with eventually differences (including level differences) between tick and tock.

3.2 Conclusion

Even if some parameters are fixed, there is a large variety of sounds that can be matched with the desired ambiences. The sound design approach, where we do not care about the technology that will be used to reproduce the sounds inside the cars (except buzzer typical frequency bandwidth), allows us to create sounds never heard before.

4. Technological Impact of Sound Design

Once we got a database of thirty "ideal" sounds, we wanted to install them on a car, simply to know what to do to make it possible. We will discuss here the case where the sound of the turn signal is played by the electronics of the dashboard. Note that some car manufacturers already use the audio system to play that sound.

4.1 Method

From the thirty sounds, we chose the three, which sound the most different:

- one with low pitch and slow decay,

- one with high pitch and quick decay,
- one with a sharp attack, and an increased overall level.

We gave these sounds to different dashboard suppliers, asking them to transpose the three target sounds into their technology and to let us listen to the transposed sounds.
We spoke together to explain why some transposed sounds were close to the target sounds, why some were far away. As such, we were able to define a way to create sounds for our future cars.

4.2 Results

Through the discussions with suppliers, we could get a better understanding about how the technology makes the sound. Two parts should be separately looked at: sound generation from electrical tension, and sound emission.
When a sound is played by the electronics of the dashboard, the sound emitter can be either a buzzer (piezoelectric or magnetic) or a loudspeaker. Whereas the frequency response of the buzzer presents strong peaks (fundamental, usually at 2kHz, and harmonics), the response of the loudspeaker is flatter, especially at high frequencies, as illustrated in Figure 3. The sound emission performances depend also on the fixation of the sound emitter and the available air volume. Note that some research deals with increasing efficiency of piezoelectric sound emitters (see [7]).

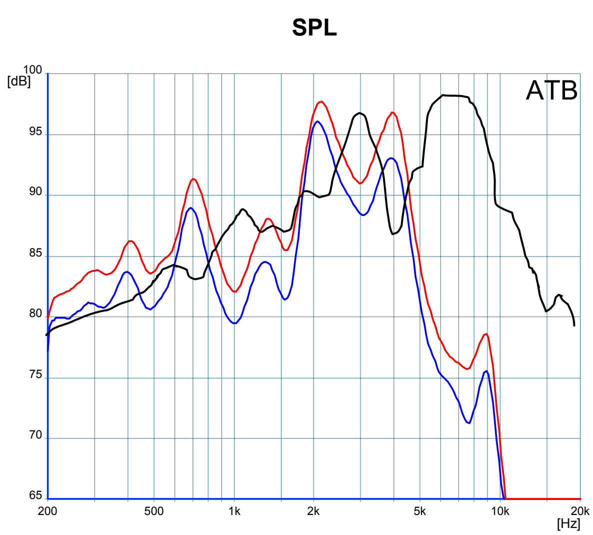

Figure 3. Frequency response of examples of buzzers (red and blue lines) and loudspeaker (black line)

We will discuss here the case where a sound generator is installed in the microprocessor (sometimes there is none!). The sound generator is able to play only monophonic sounds. In that case, the characteristics of each note are the following. They are illustrated by Figure 4:

- Total duration: defined by the duration of the pulse width modulation (PWM) signal;
- Frequency: the inverse of the duration between two square peaks of the PWM signal;
- Level: when a buzzer is used, level is adjusted by changing the duration of the peaks; when a loudspeaker is used, level can be also modified by changing peak amplitude
- Decay: it is possible to add decay within the total duration, which gives a so-called “gong” effect. Note that the duration of the decay depends on the frequency, which makes sound creation not so easy!

Note that it is not possible to change the note attack, whereas this parameter is very important for timbre.

The different sound generators do not offer the same degrees of adjustment for each characteristic. For example, the number of frequencies can be limited to 100, which does not always allow forming a perfect fifth between two notes!

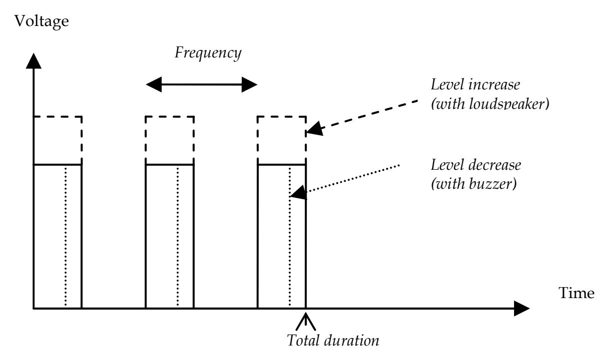

Figure 4. Sound characteristics (in italics) produced by the PWM signal

Extending the capacities of the sound generator (more degrees of adjustment), one supplier was able to create sounds close to the targets.

4.3 Conclusion

Our first intention was simply to install our new sounds on cars, but finally, the method, that consists in proposing target sounds to dashboard suppliers and inviting them to transpose them to their technology, had two consequences. As expected, it gave us (researchers in psychoacoustics) the possibility of learning about the capacities of the system. In addition, both Renault electronic engineers and dashboard suppliers discovered unknown capacities of the electronic components. In today's Renault, electronic sounds are composed of few notes, where only duration and frequency are adjusted (level stays at maximum and decay at none), we are now able to tune sounds with four parameters (duration, frequency but also level and decay) with numerous degrees of adjustment. We can expect to get nicer sounding turn signals and other sonic man machine interfaces, without any cost effect. The next step will be to use the audio system to play the sounds, which will offer us new possibilities: larger frequency bandwidth, especially at low frequencies, possible change of attack, and polyphony.

5. Conclusion

The sound quality study on turn signals provided us with information about customers' expectations and the acoustic features needed to fulfill these expectations. On this basis, and especially the idea to create sounds in harmony with material used inside the car, we worked with IRCAM Sound Design team to create a database of turn signal sounds never heard before.

Working together with dashboard suppliers, we discovered that Renault has created very poor sounds compared to the possibilities offered by the electronic components: only two parameters were used whereas four are available!

The sound design approach, that consists here of creating sounds according to our intentions and then transposing these target sounds to the technology of Renault cars, changes our habits: instead of designing sounds with normally used parameters, we pushed the known limits of the technology in order to better use it, but without changing it, so without cost effect.

6. Aknowledgment

We would like to thank Louis Dandrel for his participation in the turn signal sound design with Modalys.

The technological exploration would have been impossible without the interaction with the Renault Electronic Department and its suppliers.

References

[1] B. Saint-Loubry, *'Sound quality mark for economic cars'*. Internoise (2000)

[2] E. Rosch, *'Principles of categorization, in Cognition and categorization'* (1978)

[3] F.Guyot, *'Etude de la perception sonore en termes de reconnaissance et d'appréciation qualitative : une approche par la catégorisation'*. PhD dissertation, Université du Maine (1996)

[4] A.Guénoche, J.P.Barthelémy. *'Similitude, arbres et typicalité, in Sémantique et cognition'* (CNRS, Paris), pp205-224, (1993)

[5] C.Favre. *'Analyse en normes L1 et L0 des distances et des préférences, planification en analyse sensorielle, application au confort d'accueil des sièges automobiles'*. PhD dissertation, Université de Rennes II, (1999)

[6] G.Eckel, F.Iovino, R.Caussé. *'Sound Synthesis by Physical Modelling with Modalys'*. International Symposium on Musical Acoustics (Dourdan, France) (1995)

[7] S.E.Woodard. *'Methods to increase sound fidelity and quality produced from piezoelectric devices'*. Journal of Sound and Vibration, volume 280, pp127-240, (2005)