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Design of Electric or Hybrid vehicle alert sound system for pedestrian

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The arrival of fully or hybrid electric vehicles raised safety problems respect to the other users (pedestrians, cyclists,…) because of their low emission level. A technical solution to solve this problem is to generate an alert sound. This signal has to improve the interaction of the vehicle with its environment. Thus, the signal must carry relative information to the situation of vehicle's rolling: speed, stabilized speed, phase of acceleration/deceleration, intentions of the driver… All this without disturb the resident's quietness. How translate this in term of signal processing and how define the level of emission? We propose to present the results of tests carried out with an aim of answering those questions.

1 Introduction

The sound emitted by the vehicle remains a guarantee of safety because it allows the environment to warn of his approach. However, hybrid and electric vehicles can potentially be dangerous for pedestrians due to the absence of noise engine. At low speed (below 30 km / h), the vehicle's rolling noise operating in electric mode are not high enough to guarantee a sufficient alarm circle around the moving vehicle.

For solve the problem, one of the solutions adopted by certain manufacturers was to generate a sound at the exterior. These vehicle systems have to make outside them more audible. The principle is to equip vehicle with an external loudspeaker which diffuses a sound representative of the car's driving situation.

Although there is still no official regulations on the minimum noise for these vehicles sometimes considered too quiet, it seems appropriate to think now about the integration of a solution of "sonic interaction design" for vehicles that can operate in electric mode.

A working group on Regulatory UN Noise, the "GRB", is preparing to adopt the requirements contained in the guide on Japanese AVAS (Approaching Vehicle Audible System). These requirements would be added in Annexes 11 of ECE R51.02 (the regulation on noise outside the vehicle), if not in the RE3 (resolution of construction vehicles). The application of AVAS should be voluntary, but those vehicles which meet minimum noise should behave this "framework" regulations.

The contents of the Japanese guide, which serves as base for the study, can be divided into five main points:

-The sound must be generated automatically in a certain speed range (0 to 30km / h, 30 km / h is not fixed, being consolidated), and in both directions of travel (Front and Rear)

-The system must be deactivated by the driver with a warning when disabled (same approach as for ESP)

-The Sound must be continuous and should allow pedestrians to understand the approach and behaviour of the vehicle (speed, acceleration and deceleration)

-The exotic sounds are prohibited

The volume must not exceed that of the equivalent thermal-powered vehicle.

These recommendations suggest a wide range of possibility in terms of sound design.

We present in this article an in-situ test realized to evaluate the functionality of different sounds. First, we will describe the implementation of the test and then the results. This work was performed in part within the ANR project METASON.

2 Description

2.1 Protocol

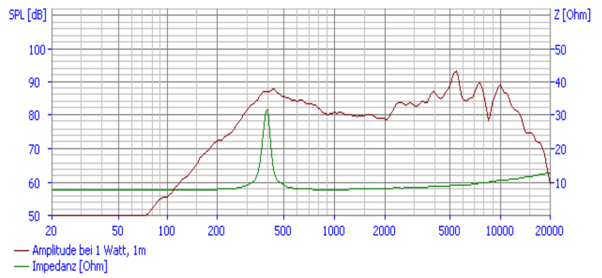
Testing was conducted on a track of our test center located in La Ferté Vidame.

Two cars were used:

-a diesel-vehicle

- an electric vehicle

The electric vehicle was prepared in order to make noise outside.



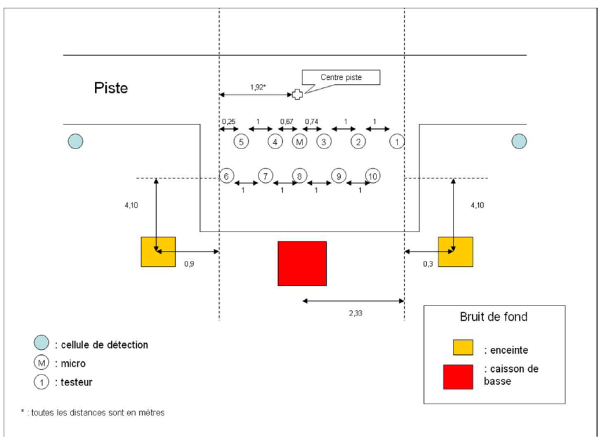
50 mm loudspeaker's characteristics

Compact loudspeaker performance shows that the [500;4000] Hz band is achievable:

The vehicles were running at 10, 30km/h and make acceleration from 10 to 30km/h. The position of the vehicle is obtained from the radar and cells located on the edge of the track.

Recruitment was done internally and consisted of 28 people in total from 20 to 60 years. No constraints on possible auditory or visual impairments.

Test was realised by group of ten people. Panel have their eyes masked and are immersed in a background (behind) with two speakers and a subwoofer. This noise comes from measurements made in Paris and was generated at a level of 60dB (A).



Test area disposal

Each panel has a "push switch" connected to the recording system.

Two questions were asked: one about the detection and another about danger and the risk.

* Detection: they had to press the button on when they detect the arrival of the vehicle.

* Danger: they press the button when they feel threatened; ie when they wouldn't cross over the road

2.2 Sound design

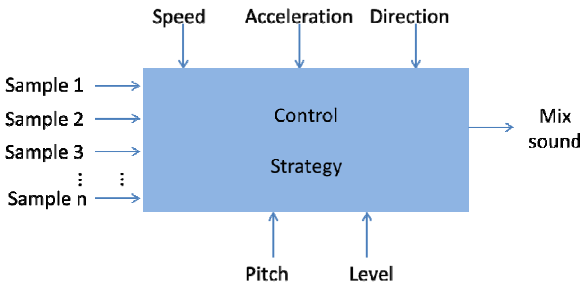
Synthesis method

The principle of AVAS is to generate real-time sound outside the vehicle to warn pedestrians of an approaching quiet vehicle. The sound is entirely controlled from information relating to vehicle's dynamic. Values of speed, acceleration and direction of travel of the vehicle are used.

A solution of sound synthesis technology to achieve the function is the synthesis by samples. It allows large possibilities in terms of sound design from a limited number of sound samples.

A synthesis module for processing sound samples has been developed on MAX / MSP in collaboration with the Laboratoire de Mécanique et d'Acoustique (LMA) of Marseille.

To stay in the metaphor of the vehicle thermal, at a first level, each sample is modified by two main parameters : pitch and level. Each of these parameters can be controlled based on vehicle parameters (speed, accel, ...). Each sample is of course controlled independently.

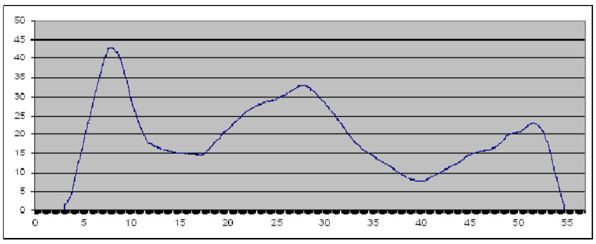


Synthesis by processing of sound sample

Sounds

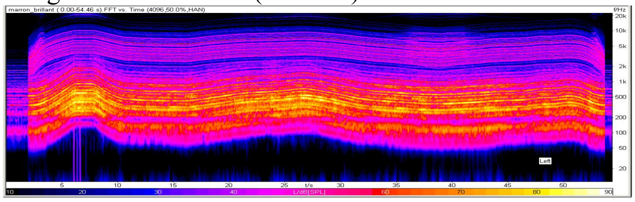
Three signals were evaluated.

Next are shown the time / frequency of these three sounds on a standard course: strong acceleration from 0 to 40km/h, strong deceleration to 15km/h, low acceleration to 35km/h, slow deceleration to 7km/hand slow acceleration to 25km/h.



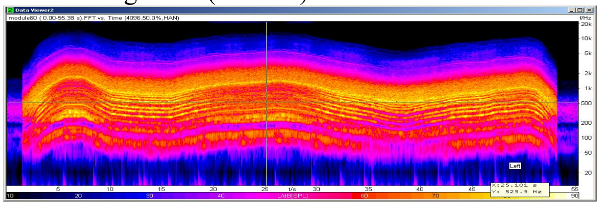
Shape of the course use to evaluate the sounds

*A first one which emerges much compared to the background noise areas (Sound 1):



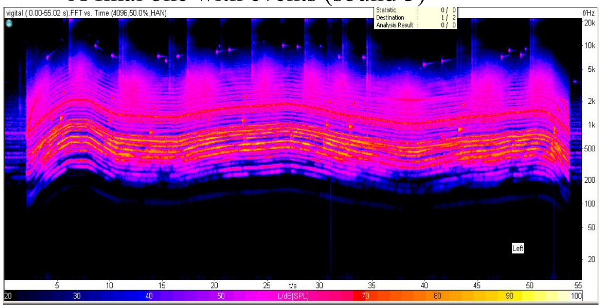
3D Time/frequency domain of sound 1

*A second much more neutral, which tends to blend into the rolling noise (sound 2)



3D Time/frequency domain of sound 2

*A final one with events (sound 3)



3D Time/frequency domain of sound 3

This allows for a view of changes of the frequency content over time and changes in spectral densities according to driving situations. One can then ask questions about the effectiveness of the system or at least how it is perceived.

Each signal was calibrated in two levels: one calls "avas" and one "loudness".

Level "avas"

This is an average level at 1 meter developed from measurements of ICE (gas and diesel)

Speed (km/h)	0	10	15	20	30
Level (dB(A) à 1m)	53	63	64	68	71

Level « avas » at 1m

Level « sonie » :

This is a level based on the loudness and thus taking into account the more perceptive aspect. Indeed, not working in the same frequency bands as ICE, loudness appears to be a more relevant parameter.

This is the model of Artemis software loudness (Zwicker and Fastl) which was used to complete an initial registration. The equalization ended listening on vehicle.

Speed (km/h)	10	15	20	30
Level Son1 (dB(A) à 1m)	63,2	63,6	62,5	65,2
Level Son2 (dB(A) à 1m)	69,9	73,7	71	69,4
Level Son3 (dB(A) à 1m)	64,7	72,8	67,2	67,5

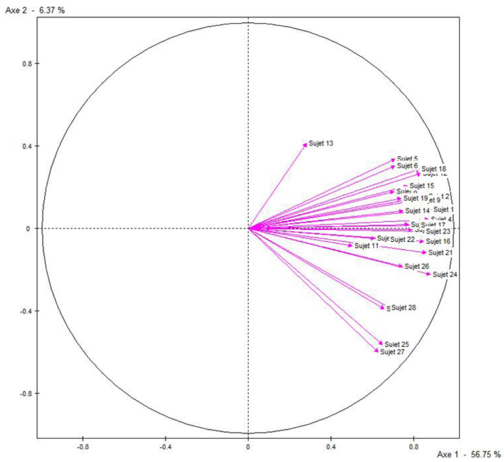
Level « sonie » at 1m

These values have been reached by means of an overall gain as a function of vehicle speed.

3 Results

3.1 Detection

The Principal Component Analysis (PCA) shows a good consensus :



PCA detection

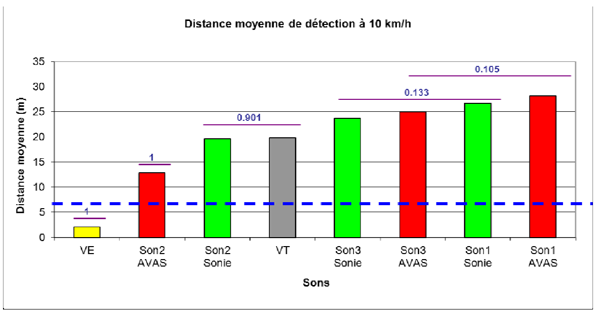
So we go to the achievement of ANOVA.
They show that:

-Electric vehicle is detected very late

-All solutions with sound revolve around the ICE

-Solutions wedged in "loudness" are more clustered than those wedged in level "AVAS"

The DUNCAN confirm all this:



DUNCAN detection at 10km/h

We can note two things:

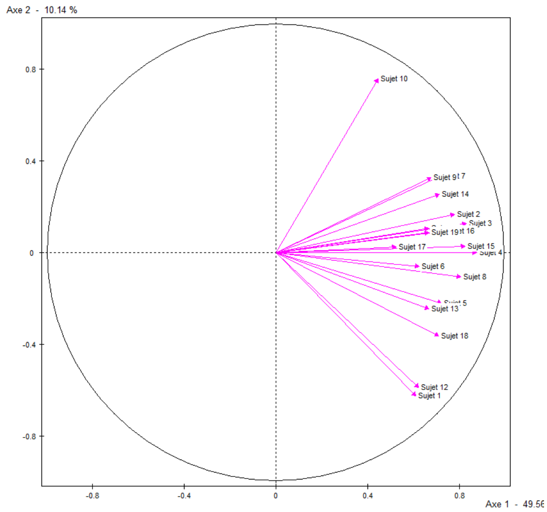
*The sound-2 "AVAS" is recessed relative to other solutions

*All solutions exceed the define security thresholds (6 meters to 10 km / h and 18m to 30km / h) or even exceed the detection level of ICE.

The detection function seems satisfied since the vehicle with the sonic interaction design is detected in most cases as well as the ICE.

3.2 danger

The Principal Component Analysis (PCA) has a lower consensus but that nevertheless remains sufficient to run statistical analyzes:



PCA danger

From risk point of view , ANOVA showed that :

-Vehicles with AVAS are between the ICE and electric

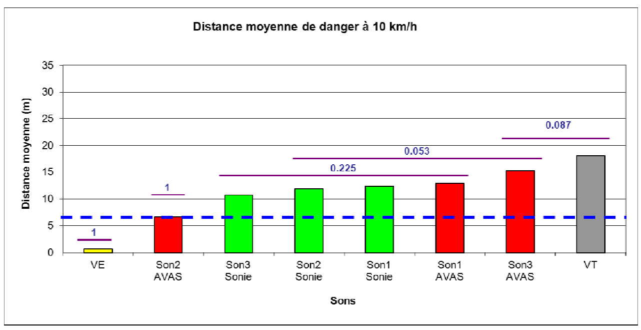
-Solutions wedged in "loudness" are more clustered than those wedged in level "AVAS" as in the detection phase.

DUNCAN shows that :

-sounds studied improve safety in relation to electric vehicles,

-outrigger "loudness" are very close,

-although vehicle with AVAS is detected at the same distance than ICE (see previous paragraph), it doesn't return the same danger.



DUNCAN danger at 10km/h

This raises the issue of evocation that will be addressed in another paper.

5 Conclusion

First of all, this test showed that a wedge in the global level (level "AVAS") is insufficient to deliver performance. "loudness" wedge, meanwhile, improves things but do not satisfy completely. An indicator taking better account of the large variations of timbre of sounds between 0 and 30 km/h has to be develop.

This test also shows that more than a detection problem, the effectiveness of the AVAS is inseparable from the evocation carried by the sound generated. This will be addressed particularly in the context of the ANR METASON and the European project eVADER.

Acknowledgments

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