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ANALYSIS AND DETECTABILITY IN URBAN ENVIRONMENTS OF AVAS FOR EVs AND HEVs

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ABSTRACT

Electric and hybrid Electric vehicles (EVs and HEVs) seem to be the future of transport in smart cities and the key for the total reduction of noise disturbance and pollution in urban areas. However, several problems have to be solved in order to guarantee the safety of these types of vehicles. So far, the use of HEVs has shown the danger of a "quiet" transport system in urban environments. This paper analyses in detail the main characteristics of several warning sounds proposed by the industry and introduce a study for their detectability depending on the urban environment.

RESUMEN

Los vehículos eléctricos e híbridos (EVs y HEVs) están llamados a ser el futuro del transporte en ciudades inteligentes y la clave para la reducción total del ruido y la polución en áreas urbanas. Sin embargo, para garantizar la seguridad vial deben solucionarse diversos problemas asociados a este tipo de vehículos. Hasta el momento, el uso de HEVs ha puesto de manifiesto el incremento del riesgo en entornos urbanos debido a la presencia de un sistema de transporte completamente silencioso. Este trabajo analiza en detalle las principales características de distintos sonidos de advertencia propuestos por la industria e introduce un estudio sobre su detectabilidad en función del entorno urbano donde se encuentre.

INTRODUCTION

Electric and Hybrid Electric Vehicles (EV and HEV) are proposed as a solution to reduce gas emission in cities, guaranteeing a good air quality in urban areas and to spare the non-renewable energy resources. Since HEV do not have the range limitations of Full EV and also not the drawback of emissions like the pure Internal Combustion Engine (ICE) vehicles, they are closer to the consumer's expectations and the current driving patterns. In fact, worldwide demand for HEVs will advance rapidly from 1.6 million units in 2010 to 4.3 in 2015, and it is expected nearly 8 million by 2020 [1]. In this context there is an increasing awareness around the issue of the environmental noise. The World Health Organisation is reporting that traffic noise causes every year the loss of at least one million healthy life-years in Europe and it is responsible for over 20.000 deaths each year via resulting heart problems, reduced sleep quality, etc. The road industry alone cannot entirely solve this problem: road users, public authorities, automotive constructors have their role to play as well. Therefore real and tangible effects in noise reduction could only be achieved by a common effort and a shared responsibility of all these actors.

On the other hand the very low noise levels due to an approaching EV or HEV could be a danger to pedestrians and cyclists, especially for a particular sensitive population as elder and blind people. Thanks to the tyre/road noise, EV may generate a sufficient noise level to warn pedestrians under some driving conditions. Nevertheless, this level can be reduced under other circumstances, particularly when the speed decreases. In this case, they are more likely to mix with pedestrian traffic. Several research laboratories and main automotive manufacturers are developing external noise generators for such vehicles but some outstanding issues remain there. The first issue is how a significant warning level can be generated in front of the vehicle, without generating important environmental noise pollution by radiating high noise levels from the sides and rear of the vehicle. The second issue is concerned with the best feature of the warning noise to use. This should be perceived to come from a vehicle but not as alarming that it will cause a startle reaction and thus increase the danger. Finally, the warning sound (WS) need to change depending on the background noise surrounding the vehicle, however it is not clear how it and under which conditions.

In order to contribute to the study of the warning sound systems, the University of Alicante, the University Miguel Hernandez, the University of Extremadura and the University of Coimbra are developing a research project funded by Directorate General of Traffic (DGT). The main objective is to propose a methodology to analyse and adapt the warning sounds that require to be fitted to electric vehicles taking into account the urban environment.

MATERIALS AND METHODS

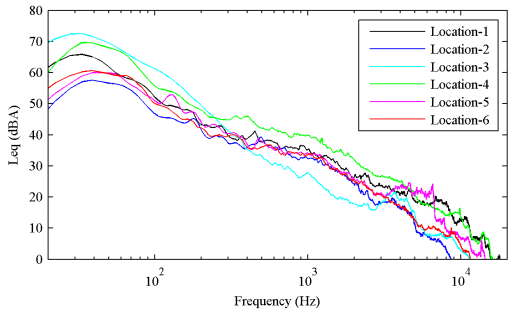
In order to determine the EVs and HEVs detectability, four main phases have been carried out:

1. Acoustic Characterisation of Urban Environments.

The categorisation methodology used to define all acoustic urban environments is based on reference [2]. The method consists of classifying the areas according to their street capacity and use in connecting different zones of a town. It is based on the generally accepted assumption that road traffic is the most important source of noise in towns, and may therefore be considered the main cause of the spatial and temporal variability of that noise.
Consequently, it is possible to structure the different environments of a typical city and the corresponding soundscapes in groups with homogenous physical characteristics. For cities with previous studies, a first selection can be made from strategic noise maps provided by the administration according the directive 2002/49/CE.

For each urban environment selected between Alicante and Elche, different sampling points were established, performing short-term measurements. In order to obtain mono and binaural acquisitions, a dummy head was used.

The measurements analysis provides information related to the sound pressure levels and spectral content for each environment. The acquired signals have been used as background noise for the psychoacoustic tests in order to evaluate masking or detectability of different warning sounds.



ID	Leq, dB(A)
Location-1	61,2
Location-2	59,9
Location-3	58,9
Location-4	65,7
Location-5	61,7
Location-6	58,7

Figure 1. Leq for selected urban environments.

2. Warning Sounds Analysis.

Several types of warning sounds are being proposed by research laboratories and the main automotive manufactures with the aim of increasing the detectability of EV and HEV without becoming new annoying sound sources [3, 4].

In order to establish a set of warning sounds, an exhaustive search was conducted to obtain public audio files. A total of 25 warning sounds were analysed, selecting those whose spectral content showed no relevant variations in time. Each audio file was first normalized in order to allow comparison between them.

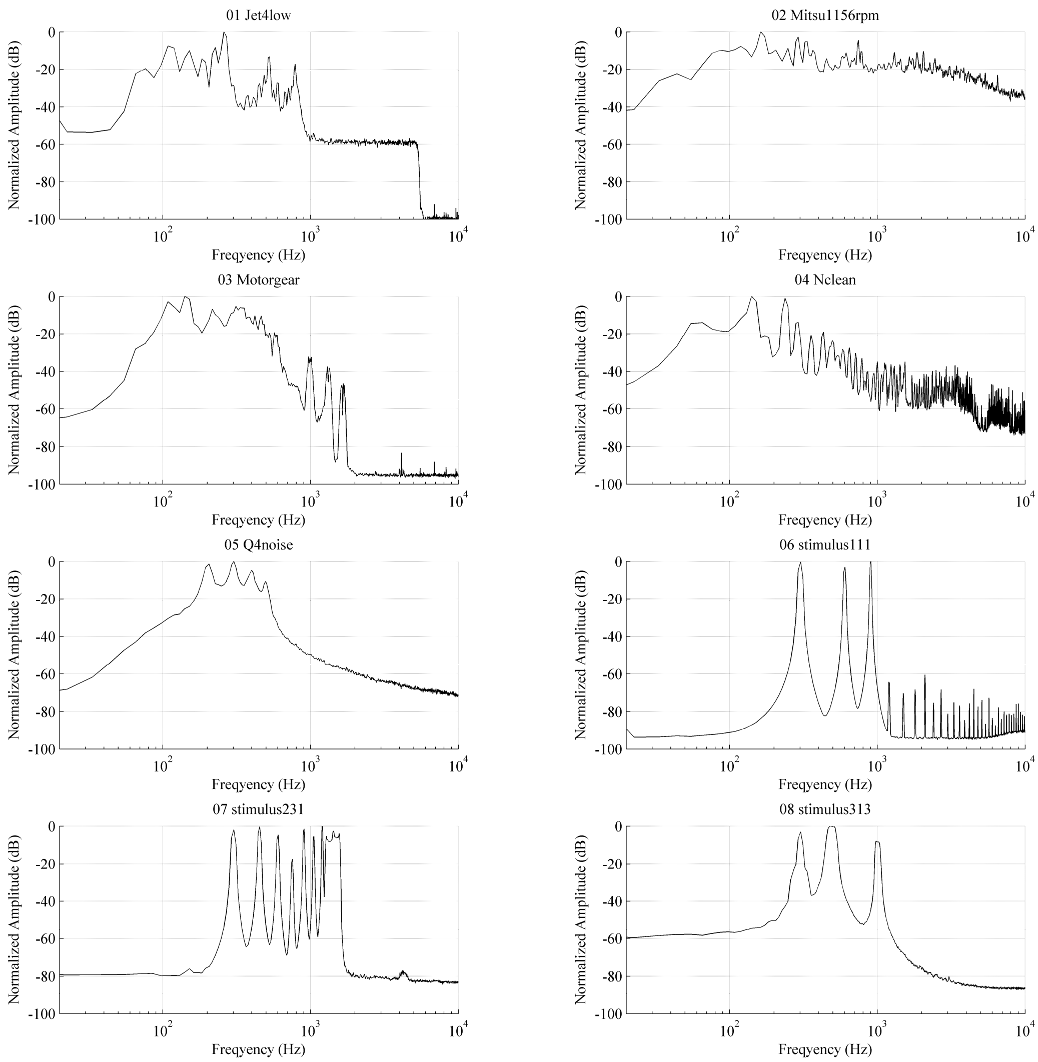


Figure 2. Warning sounds spectrum.

As shown, each sound focuses on a different frequency bandwidth, being all of them below 2 kHz. Warning sounds 1 to 5 correspond to broadband sounds while 6, 7 and 8 [5] represent tonal compositions with and without modulation.

3. Determination of the Detectability of EVs/HEVs.

Psychoacoustic tests will be performed to determine the detectability of classified warning sounds in an urban environment. For that, a real situation has been recreated: a pedestrian standing on the sidewalk, at a distance of 3 meters from the centre of the traffic lane, prepared to cross the road. Throughout the essay, different vehicle sounds, with and without AVAS, will be presented to the listener, simulating the movement in both directions. The vehicles will approach the listener individually, at a constant speed of 30 km/h, covering a distance of ±30 meters form the pedestrian. In order to increase the realism of the simulation, the vehicles will be presented together with an urban environment background noise (passage of location 4). The subject must indicate, by pressing a button, the moment he perceives the vehicle approach.

The protocol followed for the test is described below:

A. Pass-by Audio Samples Acquisition

To evaluate the detectability of vehicles, sound samples from a pass-by test were acquired. These samples will be used during the psychoacoustic tests in order to reproduce the sound events more accurately. To do this, a *Head Acoustic HSM III* dummy head was used, with a frequency sample of 44100 Hz and a bit depth of 16 bits with noise shaping algorithm. A fifth order high-pass filter with cut-off frequency of 22 Hz was used during the acquisition. The dummy head was situated at 3 meters from the centre of the traffic lane. The sound acquisition was made from ±30 meters form the dummy head.

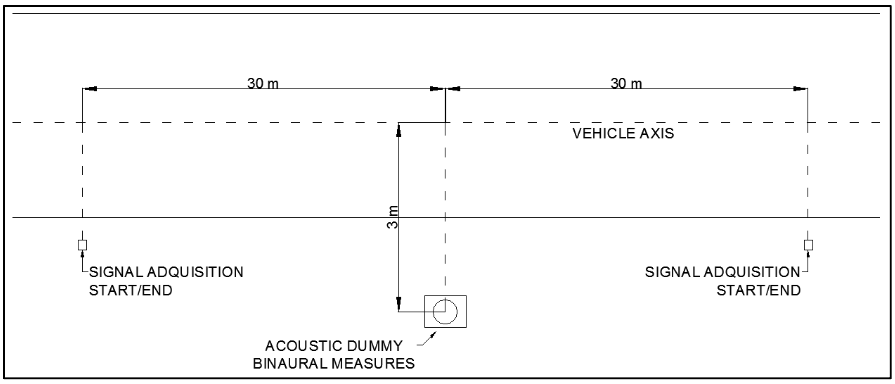


Figure 3. Pass-by test configuration for sound samples acquisition.

The measurements took place at the University Miguel Hernández of Elche, on a traffic lane with an asphalt characterization G20 + S20. The vehicle used was a Hybrid Toyota Pryus.

B. Warning Sounds Pass-by Simulation

The incorporation of warning sounds to the vehicle pass-by sound samples has been carried out by means of signal processing. For that, each selected WS has been treated to simulate a pass-by movement at a constant speed, including the frequency variation introduced by Doppler Effect and the sound pressure level attenuation by distance. In addition, the interaural delay and the frequency effect of human head have been introduced filtering the signal by means of a head-related impulse response (HRIR) [6].

C. Preparation of Sound Samples

All sound samples from the essay have been processed and conditioned for the detectability tests.

Sound Samples Selection:

Every sample from the pass-by test has been analysed and listened carefully in order to discard those useless. Some audio files present different background noises that can somehow affect the validity of the samples. For example, it is possible to distinguish wind, birds, barking, aircraft or any ambulance. These noises can significantly affect the detectability results and therefore they must be filtered or even removed.

Certain soundscapes show a higher level than the allowed by the dynamic range. This phenomenon, mainly originated by the wind gusts, causes signal distortion and therefore a significant deterioration of the recorded message. In order to eliminate part of the signal fluctuations caused by wind, all samples have been filtered by a 5-th order Butterworth high-pass filter with cut-off frequency of 80 Hz.

Sound Pressure Level, dB(A):

To perform the detectability test, a sound sample form the electric vehicle at approximately 30 km/h has been selected. The peak level emitted for this vehicles is 74,4 dB(A). As a test condition, the incorporation of warning sounds to the vehicle will not increase the peak level more than 3 dB(A). Besides, in any case the sounds exceed the HEV level running as a diesel car.

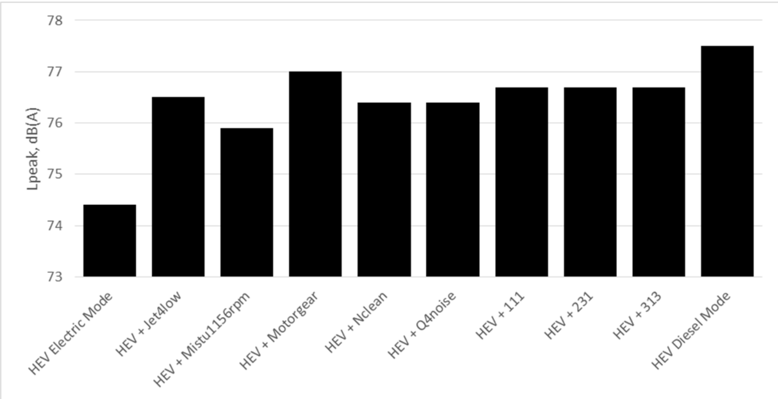


Figure 4. Warning sounds and vehicles Lpeak, dB(A).

Processing for Subjective Test:

Binaural sound samples have been obtained with an acoustic dummy head using diffuse field equalization. This equalization allows to correct the acquired signals, making possible the comparison between the measures provided by conventional microphones. To carry out the psychoacoustic tests, the diffuse field equalization must be removed so that the signals represent accurately the event.

Likewise, the use of headphones during the detectability tests may affect the accuracy of the emitted signal with respect to the real sound. The frequency response of headphones can change the spectral content of the sample, so this effect must be corrected. An inverse filter from the headphones impulse response has been used to solve the aforementioned effects.

Background Noise:

A passage from the sound sample obtained in location 4 has been selected. The equivalent sound pressure level for this background noise is 66.5 dB(A).This location corresponds to a 2 lane road with buildings positioned in one side. The recorded sound includes vehicles stopped on a traffic light next to a roundabout. A bulldozer working at a distance of 60 meters can be perceived.

D. Detectability Test

A software tool has been implemented to perform the detectability test. The application emits, over a constant background noise, different sound samples, individually and randomly. Time between sound events varies between 1 and 20 seconds. Each sound is played four times (two in the left-right direction and two in right-left direction) making a total of 40 sound events by subject.

The user must indicate the approach of a vehicle by pressing a key. At the end of the test, the application provides a text file with the time response for each sound sample.

4. Determination of the Unpleasantness for Warning Sounds.

To carry out the unpleasantness essay we have used the same sound samples of the detectability. These samples have been presented to the listener using the following test panel:

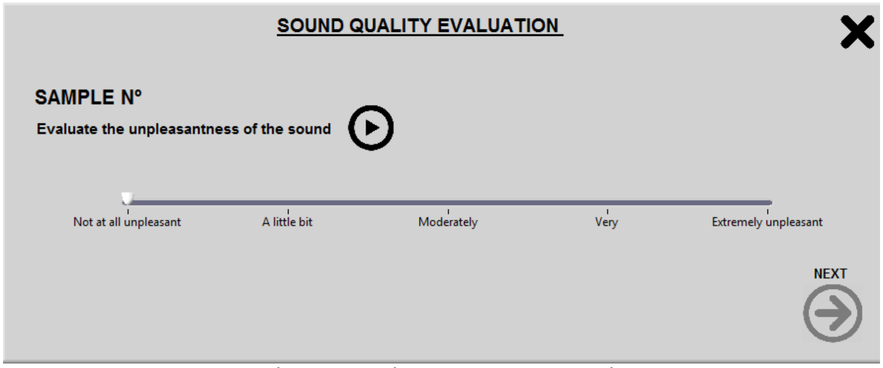


Figure 5. Unpleasantness Test Panel.

The subject must indicate the level of unpleasantness for each sound sample by means of a scroll included into the panel.

Ten different sounds with two repetitions have been presented during the test. The sound of an electric vehicle and a diesel one has been included as an anchor.

RESULTS

Detectability Test

Preliminary results show that electric vehicles require a longer response to be detected. These results can be translated as an increased risk for pedestrian since the vehicle detection takes place at a shorter distance from the listener. The difference between the detectability of electric and hybrid vehicles is 7 meters.

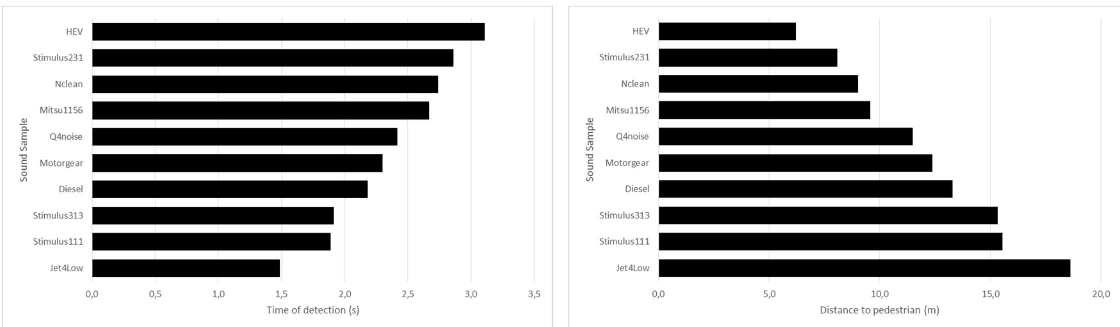


Figure 6. Time of detection (left). Distance to pedestrian (right).

The use of warning sound significantly increases the vehicle detectability, obtaining a better response for the sound samples “Jet4low”, “stimulus111” y “stimulus313”. These three sounds have high-level tonal components at frequencies near 300, 600 and 900 Hz. According to Pearson correlation coefficient, no linear relation is appreciated between the detectability of vehicle and peak level.

Unpleasantness Test

A preliminary group of 12 subjects have been polled to establish the unpleasantness of warning sound. To determine the validity of the results, the individual mean quadratic error has been calculated. All participants have a MCE below the 30% of the maximum value allowed into the test with the exception of subject 4, with a value significantly higher. The data for this subject will not be part of the results.

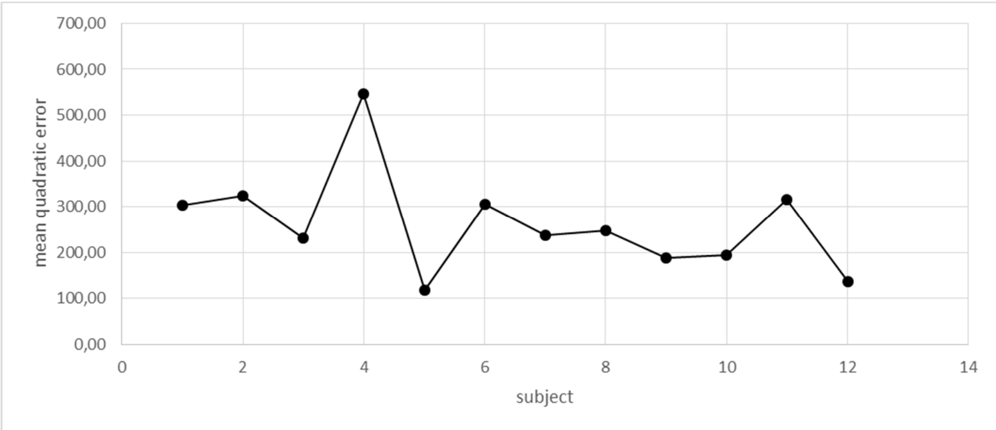


Figure 7. Mean quadratic error.

Next figure shows a preliminary sound distribution obtained by means an analysis of variance, ordered from lowest to highest unpleasantness.

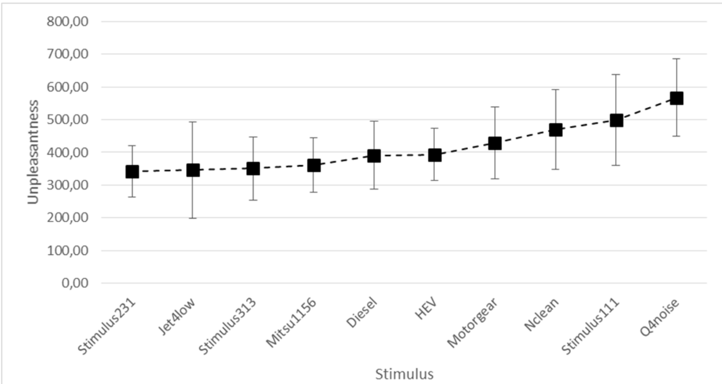


Figure 8. Unpleasantness distribution.

The addition of data from new subjects will allow the establishment of a rigorous Tukey's HSD analysis, confirming the difference between WS unpleasantness with a higher level of confidence.

The noise produced by the diesel car causes less discomfort than the electric one. This result may be due to the social acceptance of this kind of stimuli.

CONCLUSIONS

Preliminary results reveal a significant difference between the detectability of EV and ICV. Therefore, there is a real risk for pedestrians in front of the incorporation of this kind of vehicles to the urban traffic.

The use of warning sounds, especially in urban areas with low speed, can improve considerably the vehicle detectability and thereby, decrease the risk of accident. The sounds used in this study does not exceed in any case the level emitted by the diesel car and therefore does not increase the noise pollution in urban environments.

Warning sounds with better detectability, “jet4low”, “situlus111” and “stimulus313” present a similar pattern in their spectral composition. All of them include clearly marked tonal components on frequencies close to 300, 500 and 900 Hz. The results show no relationship between the peak level emitted by the vehicle and his detectability. According to the unpleasantness distribution, the sounds “jet4low” and “stimulus313” cause less annoyance to the listener and thus they will be more suitable as warning sounds in electric vehicles.

ACKNOWLEDGMENTS

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