Perceptive evaluation of road traffic noise inside buildings using a combined image and wave field synthesis system

Julien Maillard[1], Jacques Martin[1], Patricia Champelovier[2] and Jacques Lambert[2]

[1] CSTB, 24 rue Joseph-Fourier, 38400 St Martin d'Hères, France, Email: j.maillard@cstb.fr

[2] INRETS, 25, avenue François Mitterrand, 69675 Bron, France, Email: chanpelovier@inrets.fr

Introduction

Environmental pollution due to transport infrastructure has become an increasingly important subject over the past years. Research has been conducted to study its impact and various ways to reduce it. In particular, assessing the relevant parameters of the pollution and their interactions is much needed to establish efficient guiding rules for improving existing or future infrastructures. This represents a difficult task due to the complexity of the disturbance under study. On-site experiments provide real environments and, as a result, a more accurate evaluation of the disturbance. However, the relevant parameters (traffic conditions, weather, road geometry, etc.) can not be precisely controlled and their exact influence is therefore difficult to study.

This paper describes a modern approach to better evaluate the visual and audio disturbances of a transport infrastructure as perceived from inside buildings. The approach uses a virtual visual and audio display of the infrastructure to provide precise control over its characteristics. The virtual infrastructure is displayed across a window of the test room in which the subjects are asked to evaluate their comfort. The test room as well as the rest of the building is designed like a real housing apartment in order to improve the subject immersion and remove the influence of a normal laboratory environment. One of the main objectives of this tool is the study of the interaction of audio and visual disturbances. Its performance relies on the fidelity of the reproduction of the virtual infrastructure, and advanced techniques were chosen to construct both visual and audio displays. Namely, the visual display uses high resolution video restitution of combined real and synthesis images, and the audio display uses Wave-Field Synthesis (WFS) to reconstruct the associated sound field [1, 2].

After a general presentation of the test facility, the paper focuses on the restitution of the road traffic noise with the WFS system.

Laboratory facility

The test facility is located at INRETS, Bron (France). The building includes a room specifically designed to reproduce a standard living room. This room features a large window opening to the outside of the building. An external module mounted on rails can be placed against the outside wall in front of the window. This module of roughly 10 square meters is isolated from outside noise and is treated inside in order to reduce reflections and provide a quasi-anechoic environment. It is equipped with a dedicated audio and video restitution system to create a virtual display of the infrastructure directly across the test room window. Figure 1 presents a drawing of the test room and restitution module.

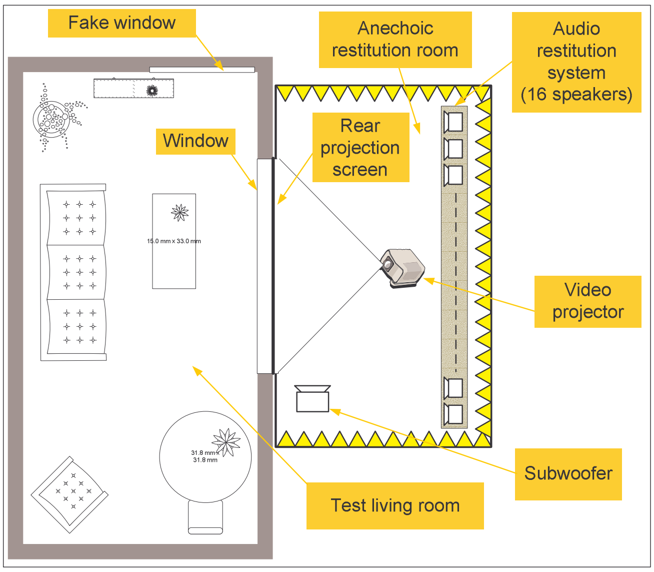

Figure 1: Test room and restitution module.

As shown in the drawing, the visual display is provided by a video projector (Barco IQ R400) and a rear projection screen directly facing the window. The audio display uses a line of speakers and a subwoofer module to construct the sound field associated with the infrastructure in front of the window. The projection screen material (Stewart) was selected to obtain a compromise between acoustic transparence and image brightness. Both audio and video restitution systems are controlled by a single PC located in a control room not shown in the above figure.

Audio display

The choice of the audio restitution system was motivated by the characteristics of the sound field associated with the road infrastructure and the area over which the restitution must be valid. The need for a fully immersive environment inside the test room requires an accurate audio display over the entire window area, assuming most of the outside noise is transmitted through this window. Also, the moving sources associated with traffic noise are located on the horizontal plane along the infrastructure. Depending on the road orientation and its distance to the building, the system must provide good sound field reconstruction for sources located in front but also far to the side of the window. Wave Field Synthesis is therefore well suited for this type of audio display as it provides accurate sound field reproduction over a large area for sources located in the horizontal plane.

The installed system uses a straight horizontal line of 16 speakers (Audax HM 100 G12) mounted in home-made enclosures (12x12x33 cm) positioned parallel to and around mid-height of the window. The speaker line is 1.9 m long using a 12 cm spacing between each speaker. The distance to the window was chosen to maintain a good restitution for sources to the side of the window while also moving away from the near field of the speakers. The set of speakers is driven by four 4-channel amplifiers (Yamaha P4050). Associated signal processing is performed on a PC equipped with two 8-channel Aardvark sound cards (Aark 24) managed by a single ASIO driver.

The restitution of the audio display includes three main steps: WFS recording of a reference traffic noise, calculation of predicted noise level, and real time restitution. A calibrated recording of real traffic is performed using a 16 microphone linear antenna, using the same spacing as the speakers. The infrastructure is chosen to have similar characteristics as the virtual infrastructure in terms of number of lanes (2 by 2 highway) and traffic density, and is recorded at the same distance (50 m). A video is also recorded simultaneously, in order to later synchronize the synthesized vehicles on the visual display with the recorded sequence.

Using Mithra© software, the noise level at the window location due to the infrastructure is estimated for the reference configuration and additional configurations related to the types of environments to study. The noise level is given as Leq levels per octave bands. The additional configurations can include various types of noise barriers, specific road cover types, and different road ground levels, among other parameters. It should be noted that the calculation does not take into account the sound reflections on the test room building since they will be naturally introduced by the restitution system. For each configuration, attenuation levels relative to the reference configuration are then obtained. The resulting attenuation gains will be applied to the recorded signals in order to introduce the effects of the parameters mentioned above. This is performed with recursive filters designed such that their frequency response closely matches the attenuation gains in each frequency band. Note that the above filters also cancel the attenuation of the rear projection screen, which was measured after installation.

Figure 2 shows a block diagram of the audio restitution algorithm. In the top part, the 16-channel calibrated audio file obtained from on-site recordings is fed to the attenuation filters associated with the current configuration. Each signal is then filtered by the WFS filter ($k = \omega / c$) and then sent to the associated speaker. The restitution algorithm also includes the restitution of synthetic audio sources which can be moved interactively or along a prefixed trajectory in front of the window. In this case, each speaker signal is gained and delayed (bottom part of the diagram) according to source and speaker position [1].

The audio system was validated by comparing binaural recordings of the real and WFS based traffic noise. In addition, subjects who were asked to evaluate the realism of the restitution as perceived from inside the test room ranked the audio system with a very high score [3].

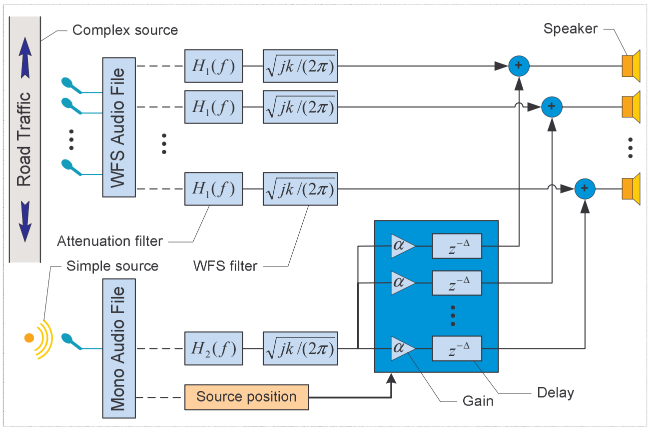

Figure 2: Block diagram of the audio synthesis and restitution system.

Conclusions

This paper presents a research tool for studying the interaction between audio and visual aspects of road traffic disturbances as perceived from inside buildings. Based on WFS audio restitution and advanced image synthesis techniques, this tool provides a physically valid audio and visual display of a road infrastructure through a building window. The ability to modify interactively both noise and visual characteristics of the road infrastructure makes the approach attractive compared to other tools which do not have such flexibility. Also, Wave Field Synthesis proved to be perfectly suited for this type of application, i.e. restitution over a large area of a complex sound field associated with a number of moving sources in the horizontal plane.

Acknowledgments

The authors wish to thank COLAS and SEGEX as partners of this project for providing road traffic measurement sites and noise barrier 3D models, respectively. The visual part of the restitution system was developed by J. C. Lombardo and S. Soubra at CSTB, Sophia-Antipolis.

References

[1] E. Verheijen, "Sound reproduction by Wave Field Synthesis." Delft: Faculty of Applied Physics, 1997.

[2] R. Nicol and M. Emerit, "Holophony versus Ambisonic: derivinga hybrid method for 3D-sound reproduction in videoconferencing.," presented at Forum Acousticum 99, 1999.

[3] P. Champelovier and D. Guérin, "Développement d'un laboratoire de simulation pour l'évaluation globale des effets environnementaux des transports.," INRETS 0232, 2002.