inter.noise 2010
noise and sustainability
13-16 June 2010 . Lisbon . Portugal
www.internoise2010.org

Simulation of Vehicle Noise in the Virtual City

Robert Smyth[1], Henry Rice[2], Paul McDonald[3], Anton Gerdelan[4]

[1 2 3] Dept. Mechanical Engineering, Trinity College Dublin, Ireland
[4] Dept. Computer Science, Trinity College Dublin, Ireland

[1]macgabhr@tcd.ie
[2]hrice@tcd.ie
[3]pmcdonal@tcd.ie
[4]gerdelan@gmail.com

Abstract
A tool that will both auralize and visualize exterior vehicle noise in real time has potential applications in environmental planning, virtual environments and the computer games industry. This paper describes the simulation of moving vehicle noise for implementation within a complex graphical urban simulation - "Metropolis" - a development platform specifically aimed at simulating real crowd behavior in central Dublin - with full audio and visual immersion of the listener. In this paper methods of vehicle simulation using a combination of sampled (power unit) and synthesized (tyre) sources are investigated. Auralization of vehicle noise is achieved through the inclusion of spatialized audio rendering (realized through FMOD sound systems) and is integrated into the graphical animation. Preliminary multi-modal tests will establish the level of detail required for a good perception of immersion to emerge.

Keywords: Auralization, Moving Vehicle Noise, Graphical Urban Simulation, Real and Synthesized Sources

1 Introduction

Road traffic noise is one of the most common environmental noise problems throughout the world and has been linked to adverse effects such as reduced quality of work and health related issues [1]. Considering that road traffic noise is the dominant source of environmental noise within the EU and that member states are facing greater responsibility to manage and assess the impact of noise on citizens, modeling road traffic noise and the efficient dissemination of these results is an important topical issue in research.

Current methods of traffic noise dissemination, including noise mapping, provide a good visual representation of the noise level in question. However, while these techniques have advanced and become quite refined relating this information to the non technical user can be difficult. Virtual 3D environments can address this problem. In this paper methods of moving vehicle simulation using a combination of sampled (power unit) and synthesized (tyre) sources are investigated and implemented within Metropolis, a virtual environment of Trinity College Dublin.

1.1 Modeling Traffic Noise

The simulation of traffic noise within the virtual city consists of two primary ideas, the auralization of road traffic noise and the implementation of this auralization within a complex graphical simulation.

1.1.1 Auralization of Traffic Noise

Recent road traffic noise auralization models have consisted of simulations reconstructed from recorded pass by test signals. This auralization technique consists of modeling separate components of vehicle noise sources independently. The creation of these source signals is based on mono recordings of straight-line pass-by recordings. The recorded signals are then reshaped into source signals by applying the knowledge of the sound propagation as an inverse problem [3].

Rodriguez et al [4] have shown that the parameter extraction of tonal components can significantly improve the simulation of dynamic vehicle noise. Tanaka et al [5] implemented an aural/visual simulation of road traffic noise where the sound pressure waveforms of the engine noise and the tire/road noise were recorded for three types of road vehicles (a car, a light truck and a heavy truck) under various running conditions. Using these sound source signals, the sound pressure waveforms for respective vehicles in an arbitrary running condition in the traffic flow were synthesized.

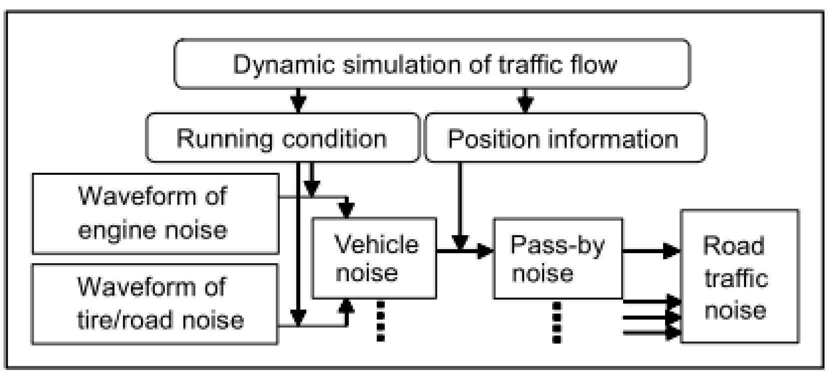

Figure 1 – An overview of the Tanaka et al Aural simulation pipeline

The road traffic noise at the roadside was auralized through a multi-channel loudspeaker system in the laboratory [5].

1.1.2 Complex Graphical Urban Environment

Traditionally, virtual 3D environments have predominately focused on the improvement of the complex graphical operations whilst deploying only a small amount of resources to the audio development. This resulted in advances in the visual complexity of 3D environments while other sensory components, such as the level of audio detail, have remained a somewhat stagnant area. However, in the past decade a greater emphasis has been placed on the auditory perception in virtual reality. The inclusion of spatialized 3D sound can satisfy several cross-modal perception issues by providing sensory input both visually and now aurally. This technique provides the sound designer with the ability to position sound sources in the virtual world, thus increasing the level of immersion. The addition of detailed rendering techniques such as head related transfer functions help to provide audio playback which is perceived as being spatially congruent with the associated visual stimulus [2].

Tsingos et al [6] have shown that including spatialized audio in complex graphical virtual environments significantly enhances the sense of realism and immersion. The Tsingos method for dynamic spatial clustering of sound sources leverages a priori knowledge of the sound sources' spectral content to exploit sound masking effects [6]. By applying a saliency metric to audio frames the augmented rendering pipeline can significantly increase the number of virtual sources which can be played simultaneously.

2 Methodology for Auralization

Vehicle noise can be broken into 3 main categories, Aerodynamic, power unit and tyre/road interaction noise. The majority of modern cars will have tyre noise dominate from 20 kph upwards while cruising and 30kph upwards while accelerating [7]. The two primary contributors to the power unit/deterministic noise are engine and exhaust noise and are mainly influenced by the engine load and the engine rotational speed. The auralization of traffic noise may be simplified into the auralization of individual vehicle components (tyre, engine etc) through a combination of sampled and synthesized sources.

2.1 Tyre Noise

Tyre/Road noise reproduction can encounter many problems due to the dynamic nature of the action. In theory, a tyre noise sample can be obtained from an individual tyre component by recording it with a microphone that moves along with the source as seen in figure 2. However, this approach is complicated by the aerodynamic noise that is generated due to turbulence and to the expensive nature of the measurement equipment.

Figure 2 – An illustration of the close proximity method employed by M + P consulting engineers using a trailer lined with absorbent materials approximating anechoic conditions while also shielding aerodynamic noise [8]

2.1.1 Tyre Noise Model

Informal pass by and coast by measurements were recorded using Behringer condenser microphones interfaced with a standard laptop via an M-Audio Fast Track Pro amplification unit. The receiver was located at a distance of 7.5m perpendicular to the direction of the vehicle motion and the data was sampled at 44100 Hz using Audacity, an open source audio sampling software package. A spectral analysis of coast by recordings displays an analogous form at various speeds within the same surface category illustrated by figure 3.

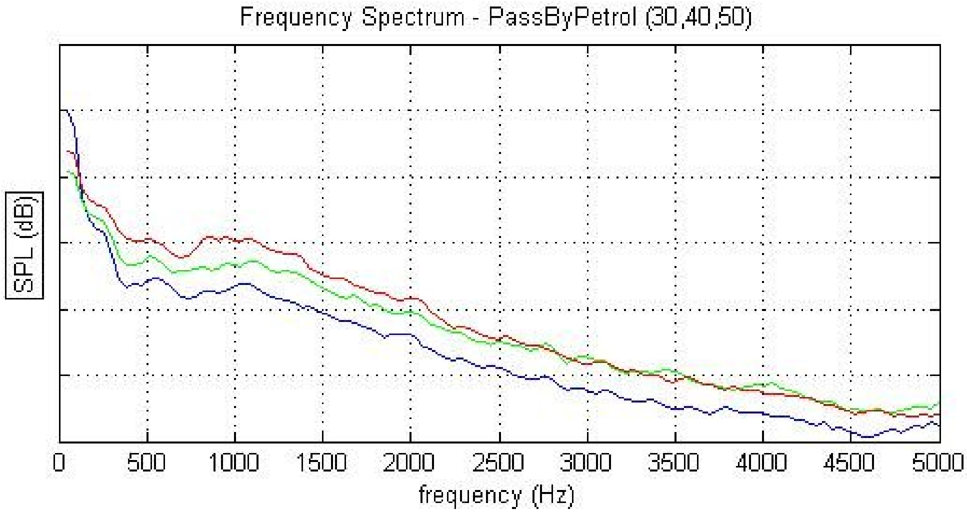

Figure 3 – Coast by recordings at various speeds (30, 40 and 50 km/hr)

For vehicle speeds greater than 20km/hr and in the neighbourhood of the reference instant, corresponding to the pass by point, the predominant noise source is the interaction between the tyre and the road surface. Isolating this section and analyzing it spectrally gives the spectrum as seen in figure 3. Applying an A-weighted filter to the spectrum above, the spectrum shape agrees with other published spectra of tyre noise and contains the peak at approximately 1000Hz which has been widely studied [6]. By normalising the A-weighted spectrum a frequency domain filter can be described which defines the shape of the tyre noise spectrum. Therefore, it is possible to simulate tyre noise by applying the filter to a wide band source signal, e.g. white noise, in the frequency domain. The result of this process is a signal which approximates closely to the actual noise produced from the tyre/road interaction.

2.2 Deterministic Noise

The deterministic components of vehicle noise can be attributed to the power unit noise. The power unit noise is mainly influenced by the engine load and the engine rotational speed.
In this study two different methods of auralizing deterministic noise are investigated.

2.2.1 Deterministic Noise Model 1

The first method involves the sampling of each individual component under static conditions. Directional power train data were recorded from a stationary vehicle, 1.0-liter, 16-valve, Toyota Yaris with VVT-i 4-cylinder engine, under no load at various speeds. These were then superimposed on the synthesized tyre noise model described earlier. Synthesizing power train noise changes to simulate varying engine speed gave qualitatively satisfactory results. This is achieved via frequency shifting applied to the pre recorded static engine noise. The resulting signals may be manipulated to simulate behavioral changes in power train noise for example acceleration. An advantage of this method is the simplicity of the measurement process. The disadvantage to this method is the absence of load to the vehicle under question which will influence the character of the noise being generated.

2.2.2 Deterministic Noise Model 2

The second method involves the extraction of deterministic components from recorded pass by tests. Standard pass by tests at speeds above 30km/hr will result in the majority of noise being produced by tyre noise. Diverse methods of shielding the production of tyre noise are being investigated. The effects of various road surfaces such as grass, compact sand, carpet/underlay and other quiet surfaces (newly laid road surface) are to be investigated to aid the production of deterministic noise. The effect of employing such road surfaces will significantly reduce tyre noise, while maintaining speeds below 80km/hr will limit the effects of aerodynamic noise. Having reduced tyre noise components, the use of a field microphone will establish the directivity patterns associated with the deterministic sources. The pass by recordings will adhere to ISO: 362 (Standard for Vehicle Exterior Noise Measurement) and will be sampled at 44100Hz using a portable data acquisition system. The position of the vehicle under question will be tracked using a laser vibrometer acting as a trigger to capture the positional information passing the reference point. The remaining stages of this process involve inverting the effect of geometric divergence and the Doppler Effect.

The Doppler Effect, the sudden change in pitch of a car horn as a car passes by (source motion) or in the pitch of a boom box on the sidewalk as you drive by in your car (observer motion), was first explained in 1842 by Christian Doppler and is given by the following equation[12].

$$f' = f_0\left(\frac{v \pm v_o}{v \pm v_s}\right) \qquad (1)$$

Where the perceived frequency (f') is related to the actual frequency (f_0) and the relative speeds of the source (v_s), observer (v_o), and the speed (v) of waves in the medium. The frequency of a signal emitted from a moving vehicle, as described above, will start out higher than a stationary signal and then continue to lower its pitch as it approaches an observer. The radial velocity of this signal will vary as a function of the angle between his line of sight and the signals velocity.

$$v_r = v_s \cdot \cos\theta \qquad (2)$$

Where v_s is the velocity of the vehicle (source of waves) with respect to the medium, and θ is the angle between the vehicle's forward velocity and the line of sight from the vehicle to the observer. This relationship between the perceived frequency and actual frequency is best illustrated through the use of an emitted tone as previously observed by Rodriguez et al [4]. Observing a pass-by test of 1000 Hz tone travelling at 50km/hr the apparent change in frequency is easily analysed as displayed in figure 4.

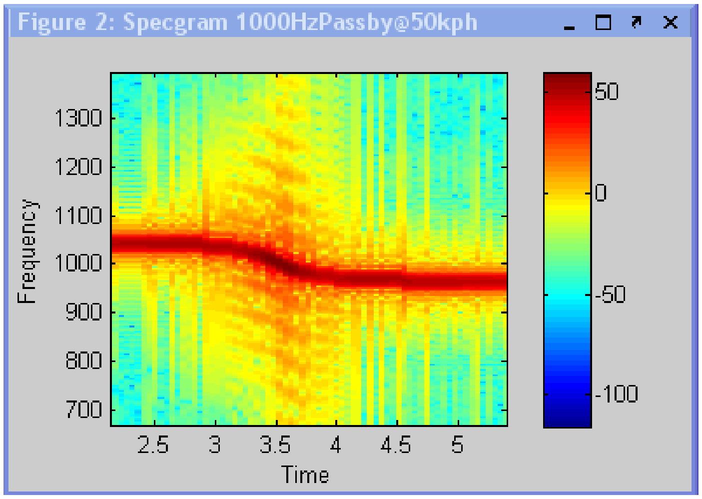

Figure 4 – Spectrogram of Pass-By test emitting a 1000 Hz tone

The relationship between the perceived and actual frequency is translated by re-sampling the data at a higher rate using low-pass interpolation. This is achieved using a Matlab script which make use of the interpolation function provided in Matlab, interp ().Where Y = INTERP(X, R) re-samples the sequence in vector X at R times the original sample rate. The resulting re-sampled vector Y is R times longer, LENGTH(Y) = R*LENGTH(X) [13]. The relationship between the radial velocity and the perceived frequency change may then be solved.

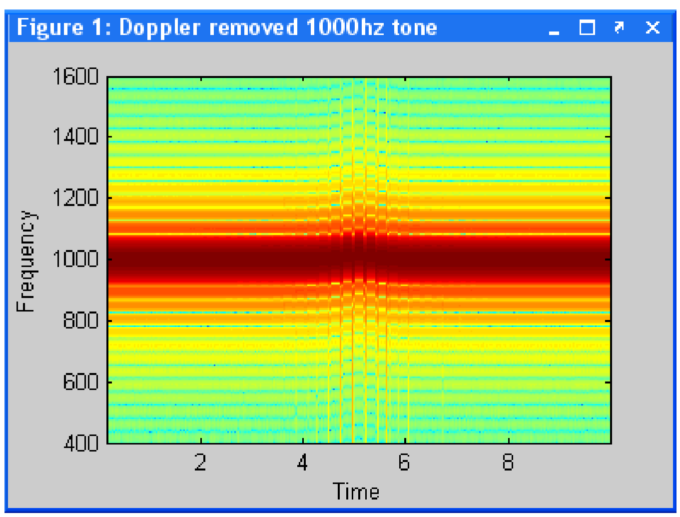

Figure 5 – Spectrogram of Pass-By test emitting a 1000 Hz tone post Doppler compensation

Once these parameters have been accounted for, the movement of the vehicle will be effectively removed and the remaining signal will be shaped by the source directivity. The signal will then be analyzed spectrally and aurally while finally being subjected to sound texturing which will extend its content to a longer duration. Through this method the noise emission due to power unit noise under load may be extracted and manipulated.

3 Auralizations in the Virtual Environment

The transformation of individual vehicle noise components into the final auralization stage is completed by modeling the individual sources as a combination of sources subjected to distance attenuation, the Doppler Effect and spatialization.

3.1 Audio System

Within the virtual environment each vehicle model consists of individually modeled components combined in 3D space positioned at their corresponding graphical positions for engine, exhaust and tyre sources. The models are then attached and configured to their associated graphical representation within the virtual environment as seen in figure 4.

The principal propagation effects required to auralize vehicle noise are distance attenuation, spatialization and Doppler Effects. This characterization process is completed through the audio platform FMOD. FMOD Ex Programmer's API and Designer are a world-leading library and toolkit for the creation and playback of interactive audio [10]. The software allows 3D sound positioning to produce basic spatialization, features distance attenuation models and a Doppler Effect algorithm. The remaining algorithm procedure involves assigning the appropriate agents with the correct sound power level. This is achieved through correlating the sound output to the actual sound power levels, calculated using the HARMONOISE method, in order to replicate real time vehicle levels.

$$L_{wp} = A_p + B_p.\frac{V - V_{ref}}{V_{ref}} \tag{3}$$

$$L_{wr} = A_r + B_r.\log\left(\frac{V - V_{ref}}{V_{ref}}\right) \tag{4}$$

L_{wp} and L_{wr} represent the noise contribution due to,

(a) the propulsion noise contribution which includes all contributions from engine, exhaust, gears, air intake, etc , and;

(b) rolling noise and aerodynamic noise.

The coefficients A_R, B_R, A_P and B_P are given in 1/3-octave bands for each vehicle, and v ref = 70 km/h [11].

The tyre noise power level is linked to vehicle speed and the road/tyre surface interaction and has been found to increase logarithmically with speed and is incorporated through equation (4). Currently the auralization model uses the static engine recordings as previously described. Informal analysis has shown that the tyre model is realistic but the power unit noise modeled is deficient

Figure 6 – A still frame of a vehicle within the virtual city

3.2 Audio Spatialization

A convincing audio rendering is a principal component of a fully immersive virtual world. In order to realize this several cross-modal perception issues such as visual and aural sensory inputs must be addressed. The use of spatialized 3D audio allows sound sources to be positioned within the virtual world providing a superior level of realism to interactive applications. The addition of detailed rendering methods such as head related transfer functions and head-tracking transforms audio playback to an advanced level which is perceived as being spatially congruent with the associated visual stimulus. This effect is best implemented through the use of headphones and illustrated as seen in figure 5.

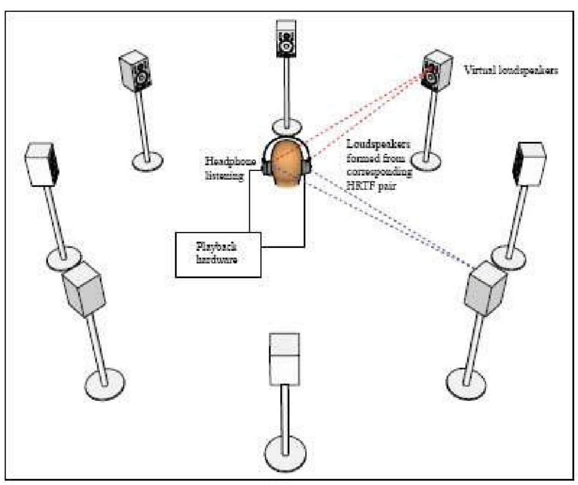

Figure 7 – An overview of the Binaural Audio Processing and simplification process [9]

4 Conclusions

Vehicle noise, as mentioned earlier, is predominately attributed to tyre noise at speeds above 30km/hr for light vehicles. The successful auralization of vehicle noise is dependent on an accurate representation of this phenomenon. However, the research presented here displays a relatively simple method for modeling tyre noise which reduces the CPU overhead but retains the subjective perception of the source. The immediate challenge to successfully auralizing complete vehicle noise stems from the deterministic noise inherent to all vehicles at certain speeds. Methods for the simulation of such sources have been presented here which will begin to address the challenge of auralizing traffic noise.

Informal analysis has shown that the tyre model is realistic but the power unit noise modeled is deficient. This will be upgraded using data from by-pass tests as described earlier. Implementation within the metropolis system is continually being updated to increase the audio level of detail.

Acknowledgments

This research was conducted within the research program “Metropolis: Supercrowds for Multisensory Urban Simulations” funded by Science Foundation Ireland.

References

[1] Lercher, P., *Environmental noise and health: an integrated research perspective*. Environment International, 1996. 22(1): p. 117-129.

[2] McDonald, P.; Dobbyn, S. *The Sound of the City: Auralization of Community Noise Data*, *InterNoise* 2009, Ottawa, Canada, August 23-26.

[3] Forssen, J.; Kaczmarek, T. *Auralization of traffic noise within the LISTEN project – Preliminary results for passenger car pass-by EuroNoise 2009,* Edinburgh, Scotland, October 26-28.

[4] Rodriguez, F,; Miyara, F. *Design and implementation of a Doppler removal method for parameters extraction and aural simulation of traffic noise, Mecánica Computacional Vol XXVIII, págs. 89-100 (artículo completo),*Tandil, Argentina, 3-6 Noviembre 2009

[5] Masafumi, T.; Fujikawa, T. *Visual/aural simulation of road traffic noise. Japan Automobile Research Institute*, Institute of Industrial Science, University of Tokyo.

[6] Tsingos, N.; Gallo, E.; Drettakis, G. *Perceptual audio rendering of complex virtual environments*. 2004: ACM New York, NY, USA.

[7] Sandberg, U., and Ejsmont, J. A., 2002. *Tyre/Road Noise Reference Book*. In-formex

[8] M+P Consulting Engineers, retrieved March 15th, 2010, from http://www.mp.nl/leaflets/leaflets.php?langID=2&page=CPX.

[9] Kearney, G., et al. *A comparative study of the performance of spatialisation techniques for a distributed audience in a concert hall environment*. 17th European Signal Processing Conference (EUSIPCO 2009) Glasgow, Scotland, August 24-28, 2009.

[10] Firelight Technologies, retrieved March 15th, 2010, from http://www.fmod.org/

[11] Peeters, Bert (M+P).; Blokland, G (M+P). *IMAGINE, The Noise Emission Model For European Road Traffic 2007*.

[12] Retrieved March 15th, 2010, from http://paws.kettering.edu/~drussell/Demos/doppler/doppler.html

[13] Retrieved March 15th, 2010, from http://www.mathworks.com/