Background traffic noise synthesis

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Abstract

Assuming sound planning is a crucial factor during planning stages of urban developments, the need of assessment tools rises. Currently, evaluation is achieved through acoustic indicators, but the they may not suffice for a holistic description of the perceived future sound environment. A way to improve this procedure is the creation of new indicators, extracted through listening tests and analysis of different acoustic scenarios, or for specific cases an audible sample of a future scenario would suffice. However, generating such scenarios using auralisation models for outdoors sound propagation is often computationally highly demanding. A simplified auralisation model is proposed, focused on background traffic noise on flat city scenarios. The proposed method relies partly on physical models for air attenuation, ground effect and spherical spreading. The Doppler effect as well as individual contributions of vehicle pass-bys are simulated with the help of modulation transfer functions. Perceived spatial imagery is realised by variable in time decorrelation of the spectra of the two channels reaching the ears of a virtual listener. As a starting point, measured power profiles are used to extract the frequency components of rolling noise. While preliminary tests against the LISTEN demonstrator have validated the model's perceived realism between 70 km/h and 90 km/h and on the range 300 m to 900 m, it is assessed through more tests for conclusive results. During these tests, auralisations are also mixed with foreground (local) traffic in order to investigate their validity in more realistic scenarios.

Introduction

The effects of extended exposure to traffic noise have been extensively documented [1, 2, 3] suggesting the development of tools for optimising the urban planning procedure. Several methods are developed like [4], but their output only include sound pressure averages over frequency. Instead, if all of the available information that one can have before a development procedure is available, there are windows of possibilities left open that can be used for assisting an urban sound planner. This information can be delivered with auralisation tools that give a perceivably realistic sound field of a future urban environment.

There are currently methods for auralising local traffic noises, but in large cities, also background road traffic noise can be of an issue. Auralisation of traffic noise, for example, is realised through the LISTEN project [5], modelling single pass-bys. As it uses explicit methods auralising each pass-by, it can be computationally heavy. The proposed method is a simplified model that attempts to model background traffic noise that is fast to compute and used alongside other auralisation tools. The model has been first described in [6], and passed through preliminary tests, and here it will be further explained and tested against a reference model, the previously validated model from the LISTEN project. The subjective listening tests include only flat-city scenarios for simplicity. Additionally, for the second part of the tests, local traffic noise is mixed with the background one.

Method

As the model's structure has been outlined in [6], complimentary details will be presented here documenting outputs during different stages of the auralisation procedure.

Input noise spectral envelopes

For the source noise, emission of a passenger vehicle data from the LISTEN project are used. These are third octave band recorded power profiles, and are passed through a normalisation stage according to [7]. The filtering process in now (comparing to [6]) tenth order third-octave band filters. White noise is feeding the filters, and using the profiles to adjust the filter coefficients, the result is an enveloped noise which resembles the vehicle's static acoustic emission. An additional step is performed here, the simulation of a cumulative Doppler effect from a traffic flow. Before setting the filters, the power profiles are duplicated and shifted up- and downwards in frequency resembling a constant shift for the left and right channel of a listener, as if the listener is head-on the direction of the traffic. The shifting procedure is realised by the appropriate energy transferring between frequency bands. This simplified method, is expected to be useful only for long distances between the listener and the road, as for short ones the relative velocity changes rapidly in time.

Propagation

Sound propagation of the modelled traffic is considered to be in a flat city scenario, so the parameters that have been considered here, are air attenuation, ground effect and fluctuations due to air turbulence. The standarised method [8] has been used for high frequency air attenuation, using the same parameters with the reference model [5]. Ground effect has been modelled similarly as well, and fluctuations in time and frequency domain due to air turbulences have been modelled according to [9]. It should be noted that ground effect and air attenuation corrections are set to be constant in time, as the situation that is modelled only includes distant noise. While propagation effects are calculated in frequency domain with Short-Time Fourier Transforms, amplitude corrections due to spherical spreading are performed in time after the spectral recomposition of the signal.

Individual pass-by events

As discussed in [6] , background traffic noise is treated as accumulated emissions from individual pass-bys. In reality though, even in large distances, fluctuations in amplitude and frequency are perceivable, and these are modeled with modulation transfer functions (MTF), described by Equation (1). Here, $x = \log_2(f/f_c)$, with f frequency in Hz and f_c the spectral point where a m=inimum is found. The amplitude of the ripples is defined by A, the ripple velocity Ω is described in cycles/octave, and ω is their velocity in cycles/second; ϕ is the phase of the function. Each channel's (left and right) MTF is configured with an according phase and direction in order to contribute in a Doppler effect percept along the spectrally shifted vehicle power profiles.

$$MTF(x) = A \cdot \sin\left(2\pi \cdot (\omega \cdot t + \Omega \cdot x) + \phi\right) \qquad (1)$$

Spatial image

While MTFs result in a virtual motion coming from phase differences between left and right channels, the overall stereo image of the resulting stimuli is at the centre of the listener as the phase components of the generated enveloped noise are the same. When using independently generated noise for each channel instead, stereo image is perceived as wide as possible. To control this, one channel is mixed with a duplicate version of the other, where the amount of mixing defines the spatial width of the perceived sound. The mixing parameter follows the MTF movement so when a vehicle is placed in front of the listener the mix would allow higher coherence between the two channels, and when cars are distributed on the left and right side coherence would be lower, resulting in a sonically wider image. The signal has been high passed at 100 Hz, as the interaural time cues containing low frequencies are important for determining the direction of a virtual source [10]. The signal path controlling coherence, can be seen in Figure 1, where x_1 and x_2 are the noise generators, H is the low pass filter, H^* its inverse for completeness of the final signal, and α is the variable mixing parameter.

Subjective tests

The model has been preliminary tested in [6] where the results encouraged conducting a test with 25 subjects to suggest or not the validation of the model. The tests similarly include parameter matching of the homogeneous traffic speed and distance, and assessing similarity between the proposed and the reference model in interaction time. A second part in the test has been also included, to assess the model under a more realistic scenario. There, the subjects assessed similarity in an A/B comparison tests between the two models, where local, foreground traffic 10 meters away from the listener was also present. The local traffic auralisation is performed with the LISTEN procedure. All the stimuli have been rendered through Head Related Transfer Functions (HRTF), while for the background traffic only the central impulse response is used. For 3 out of 25 subjects the test concluded either too early or too late. As such, their answers were discarded.

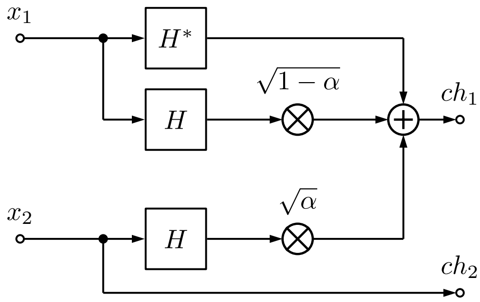

Figure 1: Signal flow of the coherence control between left and right channels

Test part	Mean	95 % C.I.	C.I. range
1 – w/o local traffic	6	6.0 - 6.4	0.4
2 – w/ local traffic	8	6.6 - 7.1	0.5

Table 1: 95 % confidence intervals of the similarity ratings means, for the different test parts

Results

In Figure 2 the similarity ratings of the first test are presented, compared to the output using the reference model. Shading shows variations in distance while the answers are grouped by traffic speed. The median is between 45 % to 65 % with the upper quartile (75 % of the answers) reaching to 80 %. The ratings reach 80 % at most of the speed profiles for 25 % of the listeners (upper quartile to upper whisker). Some outliers are also observed mainly at distances of 700 m and 900 m. When including foreground car pass-bys, the similarity ratings of the second part of the test are shown in Figure 3. Now the median lays between 60 % and 75 % while the upper quartile reaches up to 100 %. For the overall mean of similarity ratings, when local traffic is not included, the 95 % confidence interval is $6.04-6.43$, while adding stimuli of nearby pass-by events, the interval is $6.6 - 7.1$, as seen on Table 1. Confidence intervals grouped by speed are shown in Figure 4.

The box plot of Figure 5 shows the speed parameter that was asked to be matched to the reference, grouped by vehicle speed. Here, a wide spectrum of answers is evidenced, revealing inability to match the speed parameter correctly. For all speed scenarios except for 50 km/h, the range of answers varies similarly, although a trend can be noticed were the median of the answers shifts along the set speed. For 50 km/h, shorter distances hindered ability of the subjects to match speed correctly.

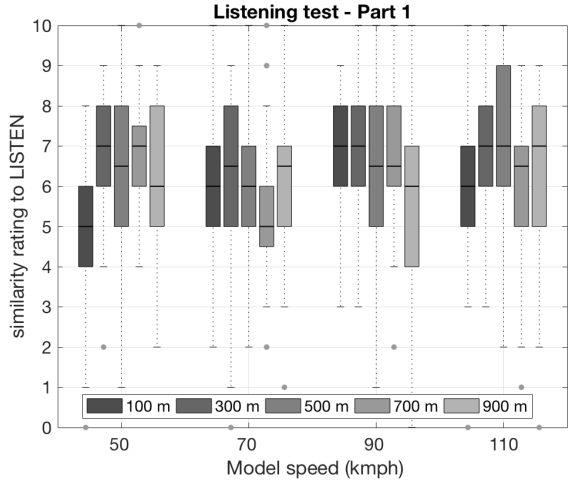

Figure 2: Similarity ratings; from light to dark, distance from 100 m to 900 m every 200 m

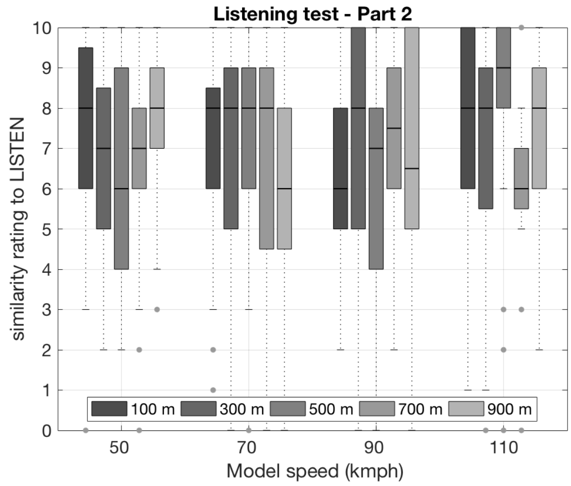

Figure 3: Similarity ratings including local traffic noise stimuli

Distance matching presented in Figure 6, is grouped by distance, where different shadings here represent different vehicle speeds. Here, answers show even larger variety, where for higher speed profiles, distance matching was unable to follow the reference. Especially for 100 m away from traffic, parameter matching shares similar values for all speed profiles.

Discussion

The model for simplified background traffic noise auralisation first presented in [6], has has been further validated. In this paper, minor changes on the functionality of the model are made, and validation is performed through subjective listening tests, against the mixed output of a previously validated reference model, presented in the LISTEN project. the validation procedure is performed in two parts. The first part questions both speed and distance perception by parameter matching, as well as general similarity between the two models. The second part assesses similarity with nearby to the listener passenger car pass-by events, resembling more realistic

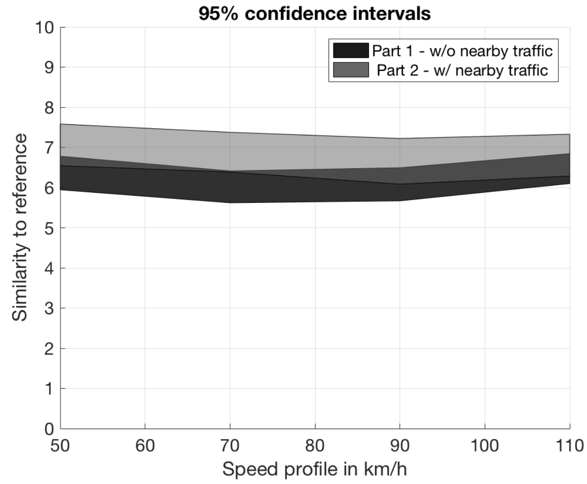

Figure 4: 95 % Confidence intervals of similarity ratings for both test parts

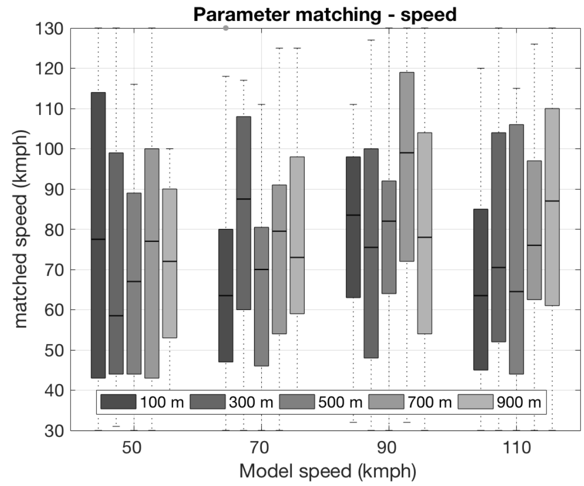

Figure 5: Speed match results; from light to dark, distance from 100 m to 900 m every 200 m

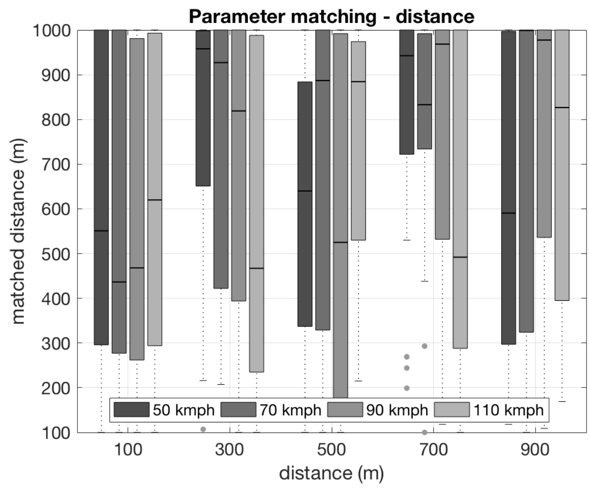

Figure 6: Distance match results; from light to dark, velocity from 50 km/h to 110 km/h every 20 km/h

scenarios. According to the results, subjects could not easily distinguish the correct speed and distance parameters of simulated traffic. The similarity ratings though, present an overall improvement on the perceived similarity of the two models with the inclusion of local events. As this can be a part of masking effects from the foreground noise, confidence intervals on the similarity ratings are calculated to ensure that their mean distributions do not overlap. The computed 95 % confidence intervals of the overall mean show this, with 6.0-6.4 for background traffic only, and 6.6 - 7.1 when adding local traffic, while their range remains similar. The perceptual similarity of the models, is shifted towards one side of the rating range, but where a stretch would be found (i.e. overlapping similarity mean distributions), there would be no indication that this simplified model could be valid combined with other elements of the acoustic scene. In Figure 4, where the 95 % confidence intervals are shown, there is no overlapping at 70 km/h, some on slower, and more on faster traffic speeds. This can be translated as a clearer improvement on the perception of realism of the proposed model at 70 km/h. A hypothesis test has also been performed, where it is shown that the mean of the similarity ratings between the two test parts do not interfere, with high significance ($P < 0.001$).

The main goal for developing this procedure is to achieve a computationally cheap tool, that is part of a wider range of auralisation methods, to be used for urban sound planning. While the model can be valid under certain circumstances, further tests are advised in order to distinguish a clearer point were it can harmonically function with additional auralised elements.

Further development posibillities

The work presented is based on a method that considers traffic as the accumulation of its acoustic elements, thus not explicitly describing them. While the opposite would be more detailed, it is also more demanding. One can attempt this mixing by including detailed modelling according the vehicles' spatial distribution on the nearest elements to the listener. Additional tonal components as well as time varying filters for source modelling can also result in better perceptions of distance and speed of traffic.

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