Real Time Auralization of Non-Stationary Traffic Noise
Quantitative and Perceptual Validation in an Urban Street

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Perceptual evaluation of noise pollution

- Ground transportation is the main source of noise pollution in cities
- Noise mapping based on long-term indicators (Laeq, ...) is not always suited for non-stationary traffic noise
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Auralization of road traffic noise brings

- a tool for the evaluation of noise annoyance based on perception
- a decision tool to help action planning in the design of quieter cities
Towards an integrated prediction and auralization tool

Support audio rendering of the sound environment
► to present different design options
► to evaluate the effects of individual or combined parameter (road geometry, road surface, noise barrier, traffic regulations, ...)

Requirements
► Render a close version of the real sound field
► Provide user interaction for comparative listening tests
Overview of the auralization framework

Off-line processing

- Rolling/engine noise recording & analysis
- Rolling/engine noise database
- Site modeling
- Calculation of acoustic paths

Real time processing

- Traffic flow module
  - Vehicle (position, speed, acceleration) time dependent
  - Rolling/engine noise synthesis
  - Moving source auralization
- Listener position
Source signal synthesis

- Real time variation of vehicle speed requires an efficient signal synthesis
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- A novel technique based on granular synthesis was proposed for the engine and tire noise components [Jagla, 2012]
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Low computational load for real time synthesis
Synchronous granular synthesis

Input
Synchronous granular synthesis

Input

Grains
Synchronous granular synthesis
Synchronous granular synthesis

Input

Grains

Output
Asynchronous granular synthesis

Input
Asynchronous granular synthesis

Input

Grains
Asynchronous granular synthesis

Input

Grains

Output

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Source signal synthesis - Psycho-acoustic validation

- Classify the signals as real or synthesized
- Three parts in each test (diesel, gas, tire)
- 10 pairs of stimuli for each part
- 40 recruited subjects (20 with training and 20 without)
- *Tested hypothesis:* synthesized and recorded noise signals are not discernible.
Source signal synthesis - Psycho-acoustic validation

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<th></th>
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<tbody>
<tr>
<td>diesel engine</td>
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<tr>
<td>gas engine</td>
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<tr>
<td>A-type tire</td>
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</table>
Psycho-acoustic validation: Diesel engine noise results

Trained subjects

- High: ✓
- Low: ✓
- Const: ✗
- Var: ✓
- All: ✗

Untrained subjects

- High: ✗
- Low: ✓
- Const: ✓
- Var: ✓
- All: ✓
Psycho-acoustic validation: Gas engine noise results

<table>
<thead>
<tr>
<th>Trained subjects</th>
<th>Untrained subjects</th>
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<tbody>
<tr>
<td>High</td>
<td>Low</td>
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<tr>
<td>✓</td>
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Psycho-acoustic validation : Tire noise results

**Trained subjects**

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<tbody>
<tr>
<td><strong>X</strong></td>
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**Untrained subjects**

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<tbody>
<tr>
<td><strong>✓</strong></td>
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<td><strong>✓</strong></td>
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</tbody>
</table>

% correct for Trained: 74%
% correct for Untrained: 51%
Propagation effects and 3D rendering

- Propulsion and rolling noise components separated according to the Harmonoise model
  - Road lane decomposition into fixed length segments
  - 3 multi-path transfer functions between each segment and receiver
  - Save N most important paths plus one “diffuse” path summing remaining contributions
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- Source-receiver path interpolation during vehicle/listener motion using
  - path coherence search based on image source transform matrix
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- FFT-based band filtering for path attenuation
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- FFT-based band filtering for path attenuation

- All paths spatially rendered using binaural, VBAP, or Ambisonics formats
On-site measurements

Gneisenaustrasse, Berlin
- East-bound lanes: standard surface
- West-bound lanes: low noise surface
- SPB measurements
- Binaural/Ambisonic recordings
Numerical model

- standard surface
- standard surface / with low barrier
- low noise surface
- low noise surface / with low barrier
- low noise surface / with low barrier / with green facades
Source-Receiver path analysis

- single vehicle
- “+”: image source contributions
- “o”: “diffuse” path contribution
- 4 second trail
Propulsion and rolling noise calibration

- constant calibration gain
- based on Harmonoise model
Comparison of auralysed and recorded sound pressure levels

- SPB analysis: recorded (red) - auralized (blue)
- distance: 7.5 m
- height: 1.5 m
- light vehicles
Auralized sound pressure levels for combined solutions

- SPB analysis: auralized sequence
- red: standard
- blue: low noise
- green: low noise + 1 m barrier
- distance: 7.5 m
- height: 1.5 m
- light vehicles

Graph showing LAFmax [dB(A)] vs. Speed [km/h] for different surfaces and barriers.
Auralized vs recorded binaural sequences

<table>
<thead>
<tr>
<th></th>
<th>auralized</th>
<th>recorded</th>
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<tbody>
<tr>
<td>Standard</td>
<td></td>
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<tr>
<td>Low noise</td>
<td></td>
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<tr>
<td>Low noise + low barrier</td>
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<td></td>
</tr>
<tr>
<td>Low noise + low barrier + green facades</td>
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<td></td>
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<tr>
<td>Calibration signal 84 dB 1000 Hz</td>
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<td></td>
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<tr>
<td>Calibration signal 84 dBA 125–4000 Hz</td>
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Conclusions

- Auralization of road traffic noise using
  - Real time processing to provide user interactivity
  - Varying vehicle speed to model non-stationary traffic flows
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  - Varying vehicle speed to model non-stationary traffic flows
- Perceptual validation of granular synthesis approach
- Quantitative validation in urban site
  - Good agreement between SPL of recorded and auralized sequences
  - Informal listening tests show auralized sequences could be used in place of recorded sequences for perceptual evaluation
On-going work

- Compare results from listening tests performed on recorded and auralized sequences to evaluate annoyance levels
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- Improve rendering of the diffuse field in dense urban environments
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- Improve rendering of the diffuse field in dense urban environments
- Extend auralization technique to trucks and public transportation vehicles
- Improve driver behavior model for realistic engine speed variations
- Validate a new approach for including effects of engine load
Thank you

Acknowledgements

- This research has been undertaken in the frame of the European project number 234306 HOSANNA
- Müller-BBM participated in the measurement campaign and provided the pass-by SPL data and tire noise CPX recordings