Geometry-based diffraction auralization for real-time applications in environmental noise

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Project overview

Auralization of Urban Environments – Real-time simulation of diffraction

Framework for research

- Funded by DFG (German research foundation)
- 3 years duration
- Currently half-time

Objectives

- Advance auralization for urban scenarios
- Perceptual evaluation

Applications in Virtual Reality

- CAVE systems
- HMDs

Image missing

Auralization of urban environments

From room acoustics to outdoor noise

Room acoustics simulation and auralization

- Enclosed space
- Strong diffuse sound field component
- Plausible also without diffraction
- Edge diffraction improves accuracy
- DSP: block-base uniform or non-uniform partitioned convolution of RIR

Image missing

Auralization of urban environments

From room acoustics to outdoor noise

Outdoor noise

- Open space
- No diffuse sound field
- Sparse wavefront arrival density
- Plausibility requires diffraction and dynamics
- Continuous sound field only with combined higher orders of reflection & diffraction

Research goals

- a) Deterministic sound path search algorithm
- b) DSP network structure for high update rates

Deterministic sound propagation path search algorithm

Principles of Geometrical Acoustics

Fermat's principle

- Follow wave front along shortest path
 - Off flat boundaries as a mirror source
 - Over edge via aperture point

Higher order simulation

- Further reflecting surfaces create a new wave front
- Further diffracting edges create a new wave front
- Complexity is exponential

Algorithm

- Mirror-based image source construction [Allen & Berkley 1979]
- Rotation-base diffraction source construction
- Modified audibility test

Allen, J. B. & Berkley, D. A., *Image method for efficiently simulating small-room acoustics*, *J. Acoust. Soc. Am.*, **1979**

Deterministic sound propagation path search algorithm

Face illumination

Gradient algorithm setup

- Preparation order = 4
- Combination order = 4

Deterministic sound propagation path search algorithm

Deterministic sound propagation path search algorithm

Deterministic sound propagation path search algorithm

Example

Illumination setup

- preparation order = 5
- combination order = 5

Computation time

- “Brute force” ~ 5ms

Deterministic sound propagation path search algorithm

Digital signal processing network structure

Single-input multiple-output (SIMO) variable delay line

Conclusion and outlook

Project: Auralization of urban environments

Auralization of diffraction

- Diffraction important for plausibility
- Deterministic propagation path algorithm based on
 - Principle: shortest path search
 - Approach: rotation-based edge diffraction

Digital signal processing

- FIR filtering not efficient
- SIMO variable delay line proposed
- Individual path rendering (enables rapid scene adaption)

Outlook

- Finish implementation of sound diffraction models (Kirchhoff, UTD, Sec. Source)
- Integrate above for environmental noise applications with real-time auralization

Reproducible research

Roadmap

Public access

- Full transparency of research approach
- Accountability for research results

Licensing

- Open source (Apache License Version 2.0)
- Open access (Creative Commons)

Implementation

- C++ diffraction code (and more)

Support

- No support (except for collaboration partners)

Code repository

git.rwth-aachen.de/ita

Thank you for your attention

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Appendix: diffraction models

Kirchhoff

- Pierce, A. D.
Diffraction of sound around corners and over wide barriers
J. Acoust. Soc. Am., 1974

Uniform Thoery of Diffraction (UTD)

- Tsingos, N.; Funkhouser, T.; Ngan, A. & Carlbom, I.
Modeling Acoustics in Virtual Environments Using the Uniform Theory of Diffraction
Proc. of the 28th Annual Conference on Computer Graphics and Interactive Techniques, ACM, 2001
- Kouyoumjian, R. G. & Pathak, P. H.
A uniform geometrical theory of diffraction for an edge in a perfectly conducting surface
Proc. of the IEEE, 1974

Biot-Tolstoy + Medwin + Svensson (BTMS, Secondary Source)

- Svensson, P.; Fred, R. & Vanderkooy, J.
An analytic secondary source model of edge diffraction impulse responses
J. Acoust. Soc. Am., 1999

Appendix: rough categorization of diffraction model complexity

Benchmark results

Model	Result length	Calculation mean (stddev)
Kirchhoff	33 complex frequency values	520ns (594ns)
UTD	33 complex frequency values	32us (31us)
BTMS	203 real values	9.3ms (848us)