Application-driven design of Auralization Systems

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Durand R. Begault
Human Factors Research and Technology Division
NASA Ames Research Center

Moffett Field, California
Two questions pertinent to auralization applications:

“What degree of fidelity is possible”?

“What degree of fidelity is necessary- does it matter”?

• hardware, software, data limitations

• how can system demands be minimized

• how some applications can use “simple” auralization
  other applications will require full multimodal capacity
Auralization is...

...the process of rendering audible, by physical or mathematical modeling, the sound field of a source in a space, in such a way as to simulate the binaural listening experience at a given position in the modeled space” 
(Kleiner, Dalenbäck and Svensson, JAES, 1993)
Auralization involves simulation of the **location** of a sound source at a point in space (azimuth, elevation, distance)...
Auralization involves simulation of the location of a sound source at a point in space (azimuth, elevation, distance)...

...and how the sound source simultaneously reveals information about its environmental context.

“Overlapping” percepts:

- image broadening
- envelopment
- distance
Acoustical environment simulation has historical basis in music

(Renaissance- baroque)

Antiphonal music:
articulation-exaggeration
of host room characteristics

Echo music:
Haydn: Das Echo

Romantic era (1830-19XX)
Program music;
notations in scores for simulating
distance, remote locations within
a simulated environment
Mahler: 2nd symphony ("Apocalypse")
Acoustic spaces have long been simulated electronically since the beginnings of signal processing.... either by echo chambers, plates and springs...

Reverberation using echo chamber, 1930s
...by use of loudspeakers arrays corresponding to sound reflections....

*University of Göttingen 1965.*

*Technical University of Denmark, Lyngby, 1992.*
..or by virtual simulation of the reverberant field
Head-tracked systems increase realism of the simulation
Relevant operating factors

- room model accuracy
- IR generation method
- absorption & diffusion data
- low frequency behavior
- measurement detail

auralization software → rendering engine → listener

Outputs

- prediction of acoustic measures
- comparison between model and real room

- acoustic transfer function difference
- dynamic interaction motivation, response
- cognitive association
- multimodal cues

- quality of specific simulation
- perceptual measure (e.g., SI)
- task performance (e.g., localization)
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auralization software

Outputs
- prediction of acoustic measures
- comparison between model and real room

rendering engine

- scenario update rate
- latency
- threshold data

listener

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ISO 3382 software calculations (n=37) from real room IRs indicate wide variability at low frequencies with non-linear decays

Brian F.G. Katz: *International Round Robin on Room Acoustical Impulse Response Analysis Software 2004*, In-press, ARLO (July 04?)
• At low frequencies (> 500 Hz), absorption coefficients difficult to quantify

• Absorption coefficients will vary depending on mounting and surface extent of the material

• Wide-range diffusion properties difficult to calculate

13 mm (0.5") gypsum board absorption coefficients (from J.S. Bradley, JAES) 1 and 2 layers
Fig. 2. Individual results of phase I (thin lines) for parameters T, EDT, C, G and LF. The thick line marks the average measurement result. As the results shown here are only intended to indicate the large differences, the curves are not marked by symbols.
“Low” frequencies not accurately modeled by geometrical acoustics (below “Schroeder Frequency”);

\[
Fs = 2000 \sqrt{\frac{T60 \text{ s}}{V \text{ m}^3}}
\]

Hybrid methods using Finite Element Modeling or BEM for low frequencies are possible

“Movement” of late reverberation due to coupled spaces

Calibrated measurements using 7 microphones in Grace Cathedral, San Francisco
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Provide real-time processing of the direct path and early reflections with good system dynamics (latency: < 70 to 100 ms, update rate: > 10 Hz minimum)

NASA SLAB system 1 direct 6 early reflections:
lateness 8 - 24 ms
scenario update rate 120 Hz
Timings and directions of direct sound and reflections

*Derivation from a “primary” model*

- Room dimension and absorption coefficients based on listening room standard *(ITU)*

- Direct sound at 0 and 120 degrees
  (*center* and *surround* loudspeaker positions)

- 1st and 2nd order reflections calculated via image model
  (*most significant* reflections identified)
Results

Anechoic speech stimuli

-35 -30 -25 -20 -15 -10 -5 0

Time delay of reflection (ms)

Direct 0, Refl. 0
Direct 0, Refl. 72
Direct 0, Refl. 151
Direct 120, Refl. 120
Direct 120, Refl. 72
Direct 120, Refl. -76

Threshold re 65 dBA SPL

Increased angle relative to direct sound results in lower thresholds
Results

Increased angle relative to direct sound results in lower thresholds

Overall levels about 10 dB higher re “anechoic” stimuli
Comparison to data from real rooms

Olive & Toole '89
(65° Reflection)
- △ - AAF Listening room
- • - Anechoic chamber

This Study
(72° Reflection)
- □ - Anechoic Speech
- ■ - Reverberant Speech
Useful guidelines for development of auralization rendering engines (example)

- Across all stimuli types and conditions, lowest thresholds correspond to **largest lateral azimuth difference** (direct sound at 120 degrees, reflection at −76 degrees).

- Reverberation (R/D ratio -20 dB) increases threshold by about 10dB for speech stimuli.

- Rule of thumb: early reflections re direct sound should be inaudible < -22 dB @ 3 ms and < -31 dB @ 15-30 ms
Late reverberation thresholds: speech, no early reflections

![Graph showing late reverberation thresholds for speech in different room sizes (Small, Medium, Large). The graph plots reverberation thresholds (speech) relative to 60 dB SPL against octave-band center frequencies (fbw = full bandwidth).]
For loudspeaker playback, background noise can mask reverberant energy (particularly the reverberant decay)
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Outputs

• prediction of acoustic measures
• comparison between model and real room

• quality of simulation (e.g., externalization)
• task performance
• perceptual measure (e.g., SI, localization)
Simple approximations of rooms and smearing of HRTF magnitude detail

Direct sound path
direct + 1 coincident reflection
direct + 6 reflections (image model)
Sound source externalization can be enabled using a limited number of early reflections
anechoic early reflections full auralization

reverberation treatment
Some perceptual measures can be shown to be equivalent between real and auralized rooms

*example: flight deck alarm*

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**Begault, “Spatially modulated audio alerts” ICAD 2003**
Given cross-modality effects, multimodal displays are also important for “accurate” auralization.
virtual object

Ground, Structural response

Walls, Windows, objects

Chairs, Tables, floor

Walls, Windows, plants

Vibration

Airborne sound

3-D audio display

head-mounted visual display

Expectation
Inter-modal coordination
Identification
Experience-adaptation

Response:
qualitative assessment
Performance metric
Summary

• Veridical representation of acoustical features depends on accuracy of input data base
  -This may limit use for specific applications

• Threshold data can enable computationally-intensive rendering engines
  -Depends on specific room and application

• Simple auralizations can provide useful perceptual cues for use in experiments and auditory displays
  -Externalization particularly useful
  -Studies verify match for specific perceptual measures between simulated and real rooms
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Durand.R.Begault@nasa.gov
http://human-factors.arc.nasa.gov/ihh/spatial/

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