CAN SPACIOUSNESS BE MEASURED DURING A CONCERT?

IOA Auditorium Acoustics, Saturday 31st October 2015
Pursuing the Spaciousness-Meter

Can Source Broadening (ASW) and Listener Envelopment (LEV) be measured directly from a music performance in a concert hall?

Approach: To test Binaural metrics that are sensitive to room acoustical properties that are known to influence on perception of Spaciousness.
Pursuing the Spaciousness-Meter

<table>
<thead>
<tr>
<th>Listeners Perceptual Aspect</th>
<th>Measure from IR</th>
<th>Measure from Music?</th>
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<tbody>
<tr>
<td>Listener Envelopment LEV</td>
<td>LLG or 1-IACCL and $G_{\text{late}}$</td>
<td>Easy?</td>
</tr>
<tr>
<td>Source Broadening ASW</td>
<td>LF or 1-IACCE</td>
<td>Difficult??</td>
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Concept: If we can hear it, we can measure it

**Correlation** and **Lateral Energy** can be measured as functions of time, with integration time $T$, e.g.

$$\text{LF}(T,t) \text{ and } \text{IACC}(T,t)$$
Measurement equipment

Maybe not
Measurement equipment

Yes, the Hair-Do is on the equipment list
Better not draw any attention
Live data acquired so far

- NY, Avery Fisher Hall
- Berlin, Philharmonie
- Helsinki, Music Centre
- Boston, Symphony Hall
- Chicago, Orchestra Hall
- Norway:
  - Oslo, Kristiansand, Stavanger, Bergen

Including some recordings with same music in different halls
Well-worn devices

Long time utilized in Broadcasting, sound recording and reproduction

Goniometer

It’s basically an x-y scope turned 45 degrees

Correlation (r) meter

$r = +1$ means $L = R$ «no stereo» «no lateral energy»

$r = 0$ means $L \neq R$ «no mono, pure stereo» «pure lateral energy»

$r = -1$ means $L = -R$ «L and R in opposite phase» «standing wave at 1kHz?»
Well-worn devices

«vertical» patterns indicate high correlation 
(r=0.5-1.0)

«round» patterns indicate low correlation 
(r=0.0-0.5)
Spaciousness - Lateral Energy - Correlation

<table>
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<tr>
<th>Spaciousness</th>
<th>Lateral Energy</th>
<th>L-R correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little</td>
<td>Small fraction</td>
<td>High (0.5-1.0)</td>
</tr>
<tr>
<td>Much</td>
<td>Big fraction</td>
<td>Low (0.0-0.5)</td>
</tr>
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Correlation and Lateral Energy Fraction is basically
Lateral Energy normalized to Total Energy
Lateral Energy is the energy of the difference signal L(t)-R(t)
Prokofiev in NY

Goniometer, integrated 10s
Binaural Lateral Fraction =0.39
R² = 0.40

100ms frame at 3.7s,
Binaural Lateral Fraction =0.18
R² = 0.69

100ms frame at 4.8s,
Binaural Lateral Fraction =0.84
R² = 0.03
Prokofiev Dance of the Knights

NEW YORK  Binaural LF = 0.39 ± 0.14

BERGEN  Binaural LF = 0.48 ± 0.19
Stravinsky
Rite of Spring

Binaural Lateral Fraction = 0.50 ± 0.14

Binaural Lateral Fraction = 0.49 ± 0.13
Solo play in Paris Philharmonie

Stalls Row K seat 03
Binaural Lateral Fraction = 0.70 ± 0.33

From IR, stage to K-03:
1-IACCe = 0.51 ± 0.15
1-IACCL = 0.88 ± 0.02
Testing sensitivity to transients

Echard plays in Philharmonie: Binaural Lateral Fractions stacked octave bands
Testing sensitivity to transients

10s of 3 balloon bursts in Philharmonie: Binaural Lateral Fractions stacked octave bands
Testing sensitivity to transients

10s of ‘Fireworks’ in reverberant room: Binaural Lateral Fractions stacked octave bands
Doing the math

Given a sequence of n samples \((1, 2, \ldots, i, \ldots, n)\) of a binaural signal pair from period \(T\), sample rate \(n/T\), and the \(i\)-th sample, pair is \(\{L_i, R_i\}\), then the (normalized) Inter-Aural Cross-Correlation over a period \(T\) is

\[
IACC = \frac{N}{D}, \text{ where }
\]

\[
N = \sum L_i \cdot R_i
\]

\[
D = \sqrt{\sum L_i^2 \cdot \sum R_i^2}
\]

Note that \(D\), the normalizer, is the product of the RMS of the L-signal and the RMS of the R-signal, over the period \(T\).
The nominator \( \sum L_i \cdot R_i \) can be obtained in different ways, e.g.

\[
L_i \cdot R_i = \frac{1}{4} \cdot [ (L_i + R_i)^2 - (L_i - R_i)^2 ]
\]

or

\[
L_i \cdot R_i = \frac{1}{2} \cdot [ L_i^2 + R_i^2 - (L_i - R_i)^2 ]
\]

If L and R are picked up by two closely spaced omni-mics, then

\((L_i - R_i)^2\) would be the figure-8-mic energy the Nominator of LF, and

\(\frac{1}{2} \cdot [ L_i^2 + R_i^2 ]\) would be the omni-mic energy of the Denominator of LF
1-IACC relates to LF

For closely spaced pick-up of L and R,

\[ L_i^2 = R_i^2 \]

and

\[ \sqrt{\sum L_i^2 \cdot \sum R_i^2} = \sum L_i^2 \]

thus

\[ \sum L_i \cdot R_i = \sum \frac{1}{2} \cdot \left[ L_i^2 + R_i^2 - (L_i - R_i)^2 \right] = \sum L_i^2 - \frac{1}{2} \cdot \sum (L_i - R_i)^2 \]

dividing by \( \sum L_i^2 \), rearranging and arriving at

\[ \frac{\sum L_i \cdot R_i}{\sum L_i^2} = 1 - \frac{\sum (L_i - R_i)^2}{\sum L_i^2} \]

Recognizing the correlation \( r \) on the left side

\[ 1 - r = \frac{1}{2} \cdot \frac{\sum (L_i - R_i)^2}{\sum L_i^2} \]
The Sagittal Plane

Non-Lateral Energy travels and arrives in or near the Sagittal Plane

Sagittal Energy = Non-Lateral Energy
Lateral Energy vs Non-Lateral Energy

- Lateral Energy sectors
- Non-Lateral (Sagittal) Energy sectors

400 Hz, 1 kHz, 4 kHz

Arrow indicates source direction contributing equally to both energy fractions.
Lateral Energy vs Non-Lateral Energy

NOTE 1: Correlation and Lateral Energy Fraction in Mid-Frequencies is relevant to Spaciousness

NOTE 2: Low Frequency sounds «surround» the listener and would contribute to Spaciousness regardless of direction

NOTE 3: Above ca 1.5kHz our hearing change strategy to use ITD envelope cues and ILD (or IID) cues
Relevant spaciousness measures

1-IACC and LF ≈ Lateral Energy normalized to Total Energy

Measures defined for the purpose of the investigation:

<table>
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<tr>
<th>Quantity</th>
<th>Notation [unit]</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Binaural Total Energy Level</td>
<td>BTL (T,t) [dB]</td>
<td>$10 \log [ L^2 + R^2 ]$</td>
</tr>
<tr>
<td>Binaural Lateral Energy Level</td>
<td>BLL (T,t) [dB]</td>
<td>$10 \log [(L - R)^2]$</td>
</tr>
<tr>
<td>Binaural Sagittal Energy Level*</td>
<td>BSL (T,t) [dB]</td>
<td>$10 \log [ L^2 + R^2 - (L - R)^2 ]$</td>
</tr>
<tr>
<td>Binaural Lateral Energy Fraction</td>
<td>BLF (T,t) [1]</td>
<td>$(L - R)^2 / (L^2 + R^2)$</td>
</tr>
</tbody>
</table>

*Sagittal Energy = Total Energy – Lateral Energy
BRIR: IACC and buildup of Lateral and Non-Lateral Energies

IACCE = 0.36
IACCL = 0.11
BRIR Buildup of Lateral and Non-Lateral energies

A1

A2

B2

Correlated Energy

Un-correlated Energy

Correlated Energy

Un-correlated Energy

Correlated Energy

Un-correlated Energy
Further work

- Determine optimum T: 33ms, 50ms, 80ms, 100ms?
- Searching for ques of Source Broadening
- Data collection
- More testing of Spaciousness-relevant measures
- Goal: To arrive at a technique that measures significant differences between rooms that we know have significantly different Spaciousness parameter values according to ISO-3382-1

[Link to online paper]
Thank you

More info?

The www center for search, research and open sources in acoustics

www.akutek.info

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