Characterization of reverberant media using the average properties of acoustic signals
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Abstract
- The multi-path propagation in a medium with low acoustic attenuation offers potentially useful information about the structural properties of this medium using only a few sensors.
- A statistical model is developed to predict a general behaviour from a limited set of experimentally accessible parameters.
- The mathematical expectations of signal envelopes and Schroeder’s integral have been analytically related to the reverberation properties and the source and sensors positions in the studied medium.
- Curve fitting (N realisations) has been applied in order to extract different parameters.

Context
- Structural characterization in reverberant conditions:
  - Randomly distributed sensors
  - Arbitrary excitation sources
- Typical reverberant signal:

\[ h_i(t) = h_i^S(t) + h_i^R(t) \]

- Early arrival (depends on source and sensor positions).
- Late reflections (statistics governed by structural properties).

\[ h_i^R(t) = \sum_{j \in \mathcal{S}} \kappa_j s(r_i, t) \]

\( \kappa_j \) number of image-sources distant from \( r_i \) to \( r_i + \Delta r_i \)
- Statistics of image-source distribution \( E[\tau] = \frac{2\pi}{S} r_i \Delta r_i \)

Theoretical developments

1) Curve-fitting on the ensemble-averaged Schroeder integral.

\[ I_e^S(t) = E\left[ \sum_{i=1}^{\infty} \left( h_i^S(t) \right)^2 \right] = \frac{A}{4} e^{-2\pi r} \]

- Estimation of \( \tau \) and \( A = \frac{2\pi}{S} D_e \).

2) Integration of the first (deterministic) wavepacket.

\[ f_0 = \int_{t_0}^{t_0+T} h_i^R(t) dt \approx D_e \]

3) \( \rho \) and \( S \) are known

- Estimation of \( S = \frac{2\pi\rho\rho}{A} \)

- Estimation of \( \rho = \frac{A S}{2\pi\rho\rho} \)

Test set-up:
- Tests on polygonal aluminum plates.
- Excitation signal: pencil-lead (experimental) or simulated source.
- Filtering by convolution with a Hann-windowed sinusoid [10-30 kHz].

Processing for parameter identification

Results

Plate surface estimation:

<table>
<thead>
<tr>
<th>Plate</th>
<th>Rectangle #1</th>
<th>Polygon #2</th>
<th>Polygon #3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated S (m²)</td>
<td>1.95</td>
<td>1.24</td>
<td>0.35</td>
</tr>
<tr>
<td>Actual S (m²)</td>
<td>2</td>
<td>1.31</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Source Localization:

(3 receivers \( \rightarrow \) intersection of 3 circles)

Conclusions

It has been shown that by using the theoretical relationship between the statistical characteristics of the received signals and the structural and source properties, it is possible to extract quantitative information from a minimal number of sensors.