Signal Processing for Hearing Instruments

Arne Leijon and many HearCom partners

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HearCom Signal Enhancement Approaches

- Multi-microphone Noise Reduction
  - Speech and Noise from different spatial directions
- Single-channel Noise Reduction
  - Speech and Noise with different signal properties
- Feedback/Whistling suppression
2005:
- Inventory, many algo’s on PC platform, not real-time
- Initial evaluation, normal hearing

2006:
- Selected/Improved algorithms, not real-time
- Preliminary evaluation, simulated hearing impairment

2007:
- Optimization for real-time, low processing delay
- Selected versions implemented on real-time platform

2008: Final Evaluation, hearing-impaired listeners
Adaptive Beamforming
Speech-distortion-weighted multichannel Wiener filter

Adaptation minimizes a weighted sum of residual noise and speech distortion energy.
Blind Source Separation

Broadband, 2nd-order statistics. Buchner et al., 2005; Aichner et al., 2006

- $Q$ independent sources, mixed into $P$ microphones.
- Adapt demixing filters to
  - minimize correlation between output signals,
  - without coloring the separated signals.
- HearCom: $Q = P = 2$ microphones, suppress 1 noise source.
Bilateral Coherence – Dereverberation/Noise Reduction

Gain response controlled by frequency-specific Bilateral Coherence
Fast Single-channel Noise Reduction

Ideally, $\hat{S}_t = e(S_t | Y_t, Y_{t-1}, \ldots, Y_0)$

Speech segm $S_t$

Noise segm $N_t$

$Y_t$

Estimator $e( )$

$\hat{S}_t$
Fast Single-channel Noise Reduction

\[ \hat{S}_t = e(S_t | Y_t, \theta^S_t, \theta^N_t) \]
**Fast Single-channel Noise Reduction**

Models for Speech and Noise include:
- Probability density functions
- Speech and Noise Spectra

and can also include prior knowledge of:
- Spectral-shape correlations (frequency)
- Spectral modulation patterns (time)
For Noise Suppression algorithms:

- Calculated performance, with model-simulated hearing losses:
- Segmental SII (segSII), (like Rhebergen et al., 2005, 2006)
- Signal-to-noise Loudness Level Difference (SNLL) (phon), (like Moore et al., 1997, 2004)

(Other measures for Feedback Suppression.)
Simulated Hearing Losses
Auditory Excitation-pattern Model

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**Test Conditions**

<table>
<thead>
<tr>
<th>Environment</th>
<th>Desired</th>
<th>Azimuth</th>
<th>Competing</th>
<th>Azimuth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-rev. room</td>
<td>Speech</td>
<td>0</td>
<td>Speech-shaped</td>
<td>60</td>
</tr>
<tr>
<td>Living-room</td>
<td>Speech</td>
<td>0</td>
<td>Music</td>
<td>60</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>Speech</td>
<td>0</td>
<td>Cafeteria Noise</td>
<td>diffuse</td>
</tr>
</tbody>
</table>

Fixed Speech Level: 70 dB SPL.
Speech/Noise ratios: 0 – 20 dB.
Baseline Result, no enhancement algorithms
Low-reverberant Room: Speech + Speech-shaped Noise 60 deg.

Algorithm effects shown as deviations from baseline.
Unilateral 3-microphone Beamforming
Low-reverberant Room: Speech + Speech-shaped Noise 60 deg.

Expected Improvement:

Speech Recognition

Speech/Noise Loudness
Unilateral 3-microphone Beamforming
Living-Room: Speech + Music 60 deg.

Expected Improvement:

Speech Recognition

Speech/Noise Loudness

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Signal Processing for Hearing Instruments
Unilateral 3-microphone Beamforming
Cafeteria: Speech + Babble.

Expected Improvement:

Speech Recognition

Speech/Noise Loudness
Expected Improvement:

**Speech Recognition**

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**Speech/Noise Loudness**

(Note extended scale)
Fast Single-channel Noise Reduction
Cafeteria: Speech + Babble.

Expected Improvement:

Speech Recognition

Speech/Noise Loudness

(Note extended scale)
Noise Reduction Benefit
Preliminary Calculated Results with Model-simulated Hearing Losses

- Multi-microphone Beamforming:
  - Improves speech recognition in many environments
  - Improves Signal/Noise Loudness Ratio
  - More severe hearing loss →
    - smaller intelligibility improvement at given SNR.
    - about equal SNR threshold improvement.
Noise Reduction Benefit
Preliminary Calculated Results with Model-simulated Hearing Losses

- **Multi-microphone Beamforming:**
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  - **More severe** hearing loss →
    - **smaller** intelligibility improvement at given SNR.
    - **about equal** SNR threshold improvement.

- **Single-channel noise reduction:**
  - Probably no improvement of speech recognition
  - Improves Signal/Noise Loudness Ratio