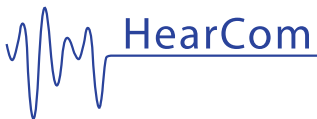


Signal Processing for Hearing Instruments

Arne Leijon and many HearCom partners

Workshop Hearing Screening and Technology, Brussels 28 Jan 2009



KTH Electrical Engineering

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

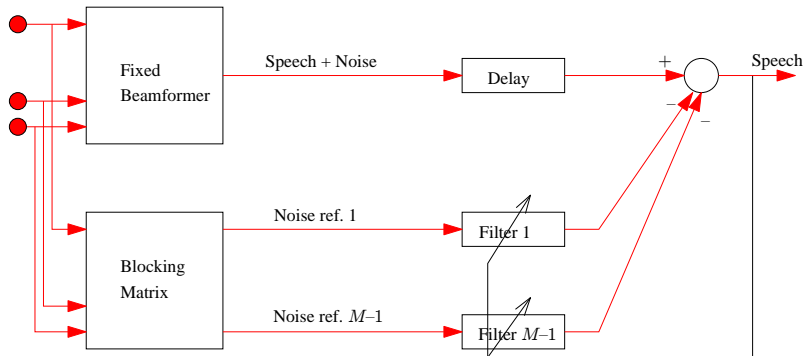
HearCom Algorithm Development and Evaluation

- 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

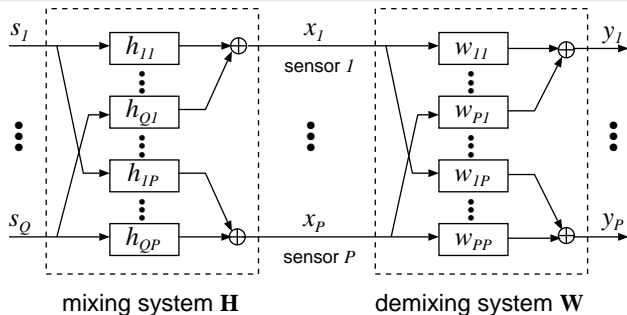
M microphones



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

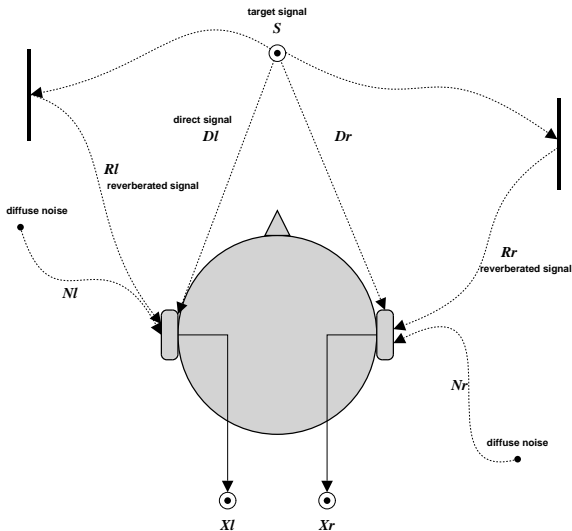
Blind Source Separation

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



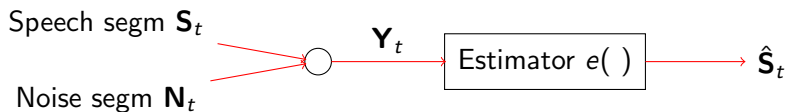
- Q independent sources, mixed into P microphones.
- Adapt demixing filters to
 - minimize correlation between output signals,
 - without coloring the separated signals.
- HearCom: $Q = P = 2$ microphones, suppress 1 noise source.

Bilateral Coherence – Dereverberation/Noise Reduction



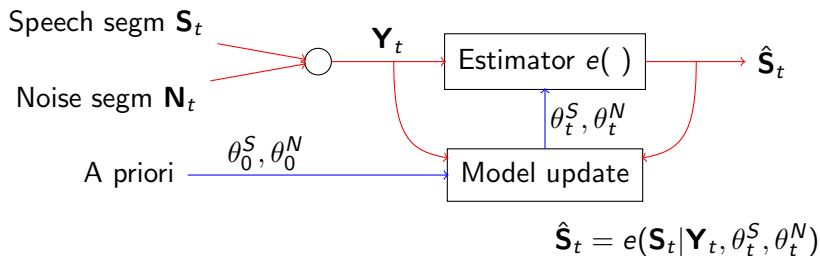
Gain response
 controlled by
 frequency-specific
 Bilateral Coherence

Fast Single-channel Noise Reduction



$$\text{Ideally, } \hat{\mathbf{S}}_t = e(\mathbf{S}_t | \mathbf{Y}_t, \mathbf{Y}_{t-1}, \dots, \mathbf{Y}_0)$$

Fast Single-channel Noise Reduction



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)

Preliminary Performance Evaluation

MatLab algorithm implementations

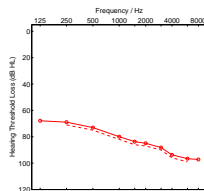
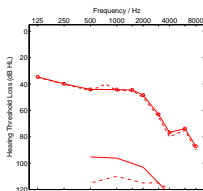
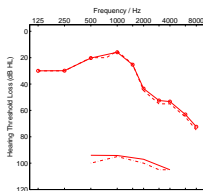
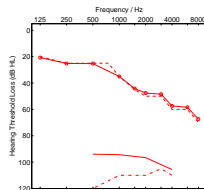
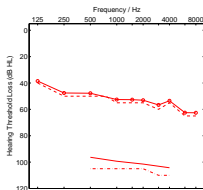
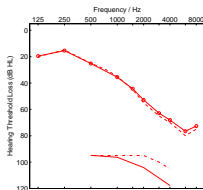
For Noise Suppression algorithms:

- 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



Test Conditions

Environment	Desired	Azimuth	Competing	Azimuth
Low-rev. room	Speech	0	Speech-shaped	60
Living-room	Speech	0	Music	60
Cafeteria	Speech	0	Cafeteria Noise	diffuse

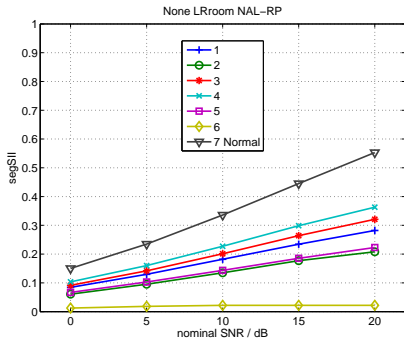
Fixed Speech Level: 70 dB SPL.

Speech/Noise ratios: 0 – 20 dB.

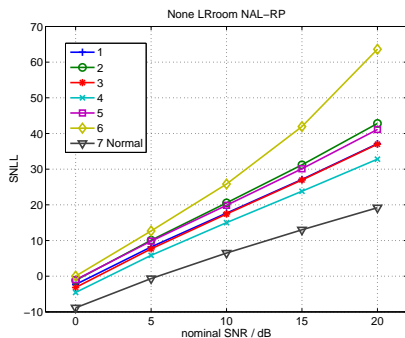
Baseline Result, no enhancement algorithms

Low-reverberant Room: Speech + Speech-shaped Noise 60 deg.

Speech Recognition



Speech/Noise Loudness



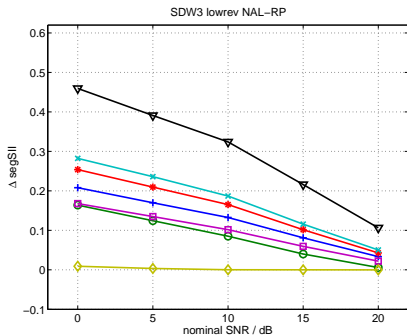
Algorithm effects shown as *deviations* from baseline.

Unilateral 3-microphone Beamforming

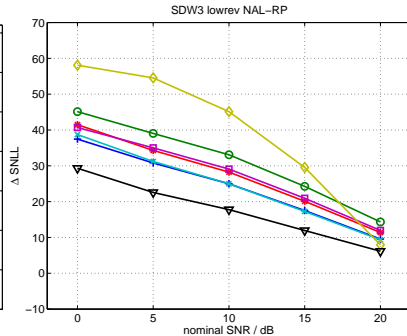
Low-reverberant Room: Speech + Speech-shaped Noise 60 deg.

Expected Improvement:

Speech Recognition



Speech/Noise Loudness

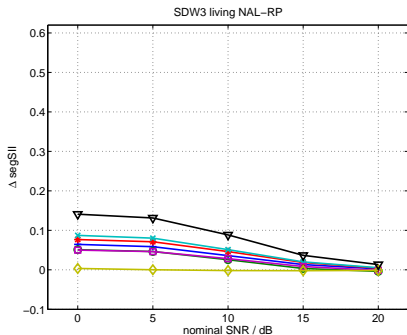


Unilateral 3-microphone Beamforming

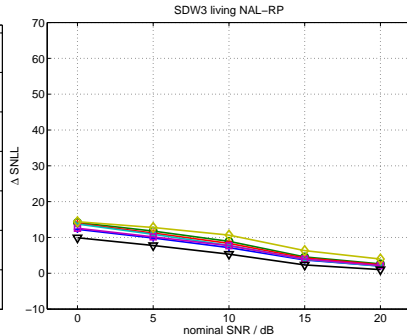
Living-Room: Speech + Music 60 deg.

Expected Improvement:

Speech Recognition



Speech/Noise Loudness

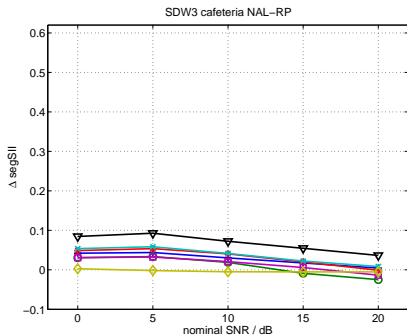


Unilateral 3-microphone Beamforming

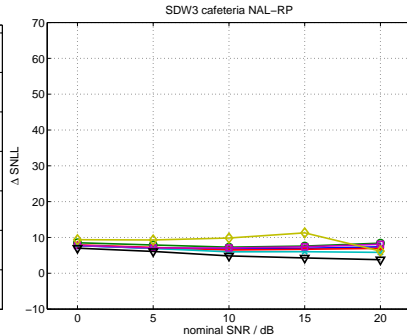
Cafeteria: Speech + Babble.

Expected Improvement:

Speech Recognition



Speech/Noise Loudness

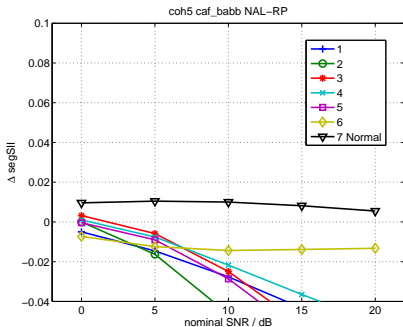


Bilateral Coherence Dereverberation/Noise Reduction

Cafeteria: Speech + Babble.

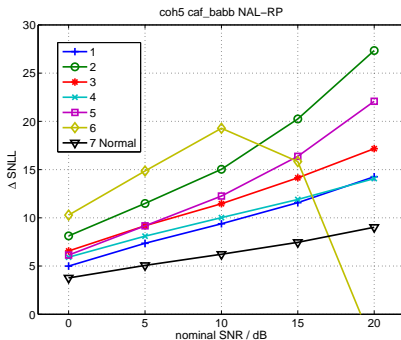
Expected Improvement:

Speech Recognition



(Note extended scale)

Speech/Noise Loudness

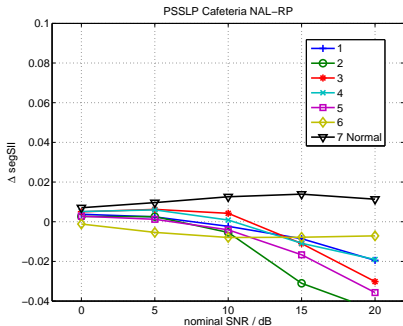


Fast Single-channel Noise Reduction

Cafeteria: Speech + Babble.

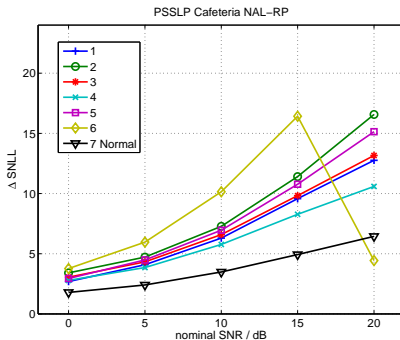
Expected Improvement:

Speech Recognition



(Note extended scale)

Speech/Noise Loudness



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

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