Real-Time Evaluation of an RTF-Steered Binaural MVDR Beamformer Incorporating an External Microphone

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Problem Statement

- Noise reduction:
  - Background noise reduces intelligibility of speech
  - Equal amplification of desired source and noise in hearing aids without filtering
- Cue preservation:
  - Awareness of acoustic scenes
  - Without cues mismatch between acoustic and visual information

In this Poster a real-time implementation of an RTF-steered **binaural MVDR** beamformer is presented and evaluated. A computationally cheap RTF estimator, which exploits an **external microphone**, is used [1, 2].

Signal Model

- Microphone signals stacked in one vector:

$$\mathbf{y} = [Y_{L1}(\omega), Y_{L2}(\omega), Y_{R1}(\omega), Y_{R2}(\omega)]^T, \qquad \bar{\mathbf{y}} = [\mathbf{y}^T, Y_E(\omega)]^T$$

- Noisy signal $\mathbf{y}$ decomposed into speech and noise:

$$\mathbf{y} = \mathbf{x} + \mathbf{n}, \quad \text{with} \quad \mathbf{x} = \mathbf{a}S$$

- Covariance matrices:

$$\mathbf{R}_y = \mathcal{E}\{\mathbf{y}\mathbf{y}^H\}, \quad \mathbf{R}_x = \mathcal{E}\{\mathbf{x}\mathbf{x}^H\}, \quad \mathbf{R}_n = \mathcal{E}\{\mathbf{n}\mathbf{n}^H\}$$

Binaural MVDR

Aims on minimizing output noise PSD while preserving the desired source:

$$\min_{\mathbf{w}} \mathbf{w}^H\mathbf{R}_n\mathbf{w}, \quad \text{s.t.} \quad \mathbf{w}^H\mathbf{h} = 1 \quad \Rightarrow \text{Solution:} \quad \mathbf{w} = \frac{\mathbf{R}_n^{-1}\mathbf{h}}{\mathbf{h}^H\mathbf{R}_n^{-1}\mathbf{h}}$$

Requirements:

- Two reference microphones (one at each side of the head) and two RTF vectors [3] with corresponding selection vectors $\mathbf{e}_{L/R}$
  $\Rightarrow$ Spatial perception
- Needs estimate of $\mathbf{R}_n$, obtained by SPP [4]

RTF Estimation Exploiting an External Microphone

Assuming sufficiently large distance between local array and external microphone and diffuse noise

$$\Rightarrow \quad \mathcal{E}\{\mathbf{n}N_E^*\} = \mathbf{0}$$

Extended covariance matrix:

$$\bar{\mathbf{R}}_y = \mathcal{E}\{\bar{\mathbf{y}}\bar{\mathbf{y}}^H\} = \begin{bmatrix} \mathbf{R}_y & \mathcal{E}\{\mathbf{y}Y_E^*\} \\ \mathcal{E}\{\mathbf{y}^H Y_E\} & \phi_{y,E} \end{bmatrix} = \begin{bmatrix} \mathbf{R}_y & \mathcal{E}\{\mathbf{x}X_E^*\} \\ \mathcal{E}\{\mathbf{x}^H X_E\} & \phi_{y,E} \end{bmatrix}$$

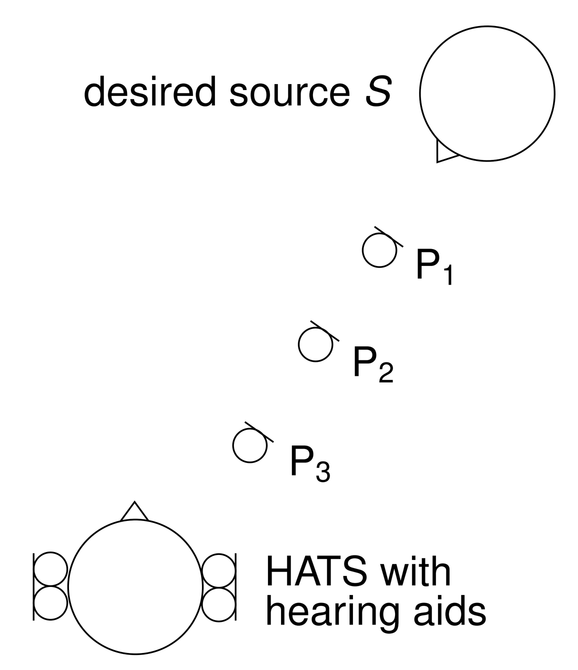
Adaptive estimation of RTF vector:

$$\mathbf{h} = \frac{\mathcal{E}\{\mathbf{y}Y_E^*\}}{\mathcal{E}\{Y_{ref}Y_E^*\}}$$

Algorithm 1: RTF Estimation Using Spatial Coherence
Input: $\bar{\mathbf{y}}(l)$, $\bar{\mathbf{R}}_y(l-1)$, $SPP(l)$
Output: $\mathbf{h}(l)$, $\bar{\mathbf{R}}_y(l)$
Parameter: α_y
for right and left **do**
  for all k **do**
    if $SPP \geq 0.6$ **then**
      $\bar{\mathbf{R}}_y(l) = \alpha_y\bar{\mathbf{R}}_y(l-1) + (1-\alpha_y)\bar{\mathbf{y}}(l)\bar{\mathbf{y}}(l)^H$;
    else
      $\bar{\mathbf{R}}_y(l) = \bar{\mathbf{R}}_y(l-1)$;
    $\mathbf{h}(l) = [\mathbf{I}, \mathbf{0}]\frac{\bar{\mathbf{R}}_y(l)\mathbf{e}}{\mathbf{e}_{L,R}^T\bar{\mathbf{R}}_y(l)\mathbf{e}}$;

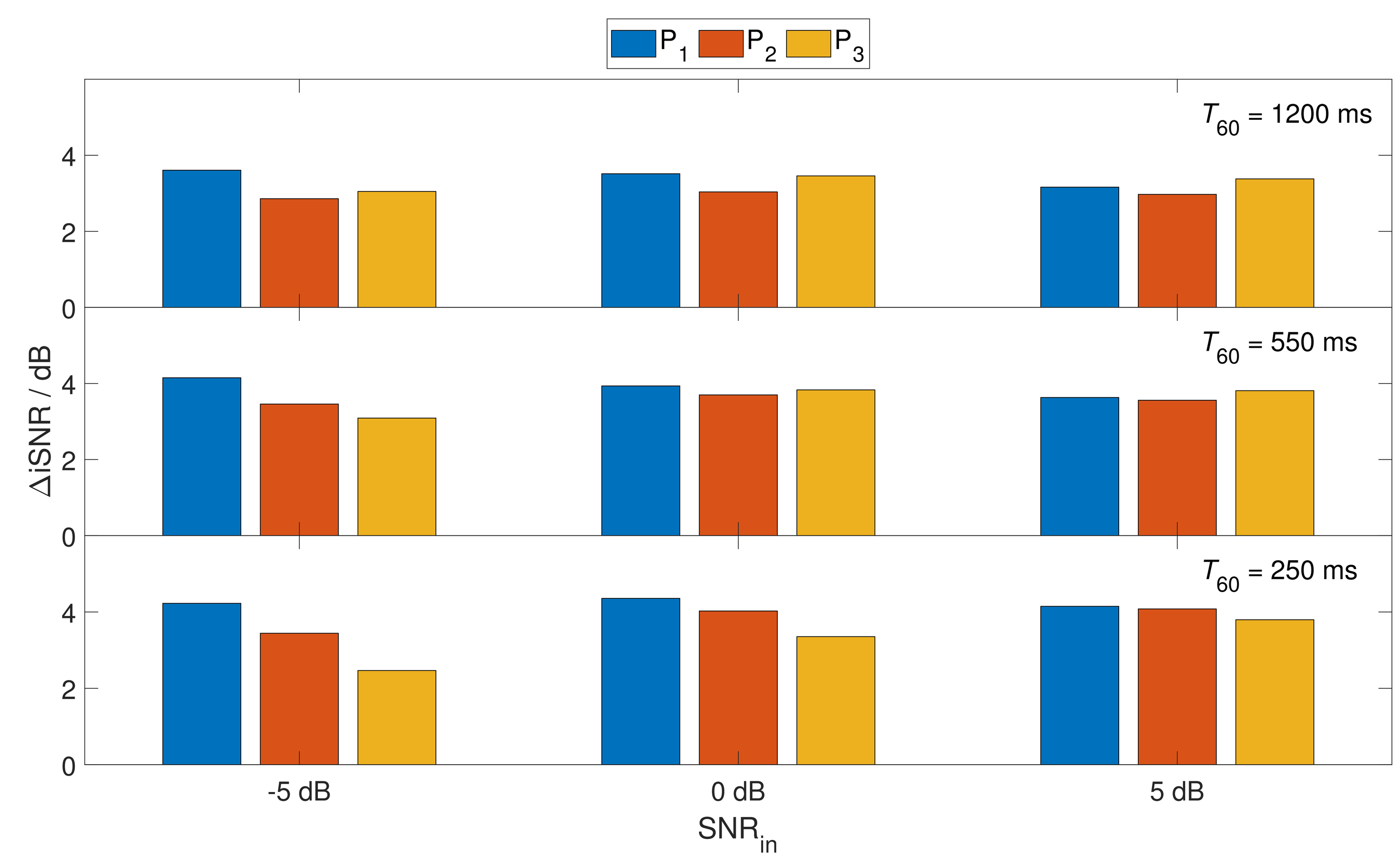
Experimental Setup

Scenario 1:
Speaker to the right (d_S = 2 m), external microphone to the right (d_E = 1.5 m), T_{60} = 600 ms, SNR_{in} = 0 dB
Scenario 2:
Speaker to the left (d_S = 2 m), external microphone to the right (d_E = 1 m), T_{60} = 600 ms, SNR_{in} = 0 dB
Scenario 3:
Moving speaker (from right to left), lapel microphone, T_{60} = 600 ms, $SNR_{in} \approx$ 0 dB



1. **Measurements & Setup**
   - HATS in *Variable Acoustics Laboratory* University Oldenburg
   - One active speaker in diffuse babble noise
   - T_{60} = {250, 550, 1200} ms
   - SNR_{in} = {-5, 0, 5} dB
   - Three different positions of external microphone
2. **WOLA Framework**
   - Sampling rate: f_s = 32 kHz
   - FFT length: n_{fft} = 1024
   - Sqrt. Hann Window, 50 % overlap
   - Ref. mics.: front on left and right side (channel 1 and 3)
3. **Performance measures**
   - Intelligibility weighted SNR improvement ΔiSNR

Results



- Applicability of SC-based RTF estimator in real-time framework
- Overall high stability in various acoustic scenarios
- More stable at high input SNR
- Better noise reduction performance at lower T_{60} and higher input SNR in external microphone

Conclusion & Outlook

In this real-time implementation, it has been shown that the RTF-steered MVDR beamformer using the SC method, leads to

✓ Good noise reduction performance
✓ Cue preservation of the desired source
✓ Low computational complexity

But

✗ Needs external microphone

- More external microphones with combined RTF estimates
- Post-filtering
- GSC implementation

References

[1] N. Gößling and S. Doclo. RTF-based binaural MVDR beamformer exploiting an external microphone in a diffuse noise field. In Proc. ITG Conference on Speech Communication, pages 106–110, Oldenburg, Germany, Oct. 2018.

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[3] D. Marquardt. Development and Evaluation of Psychoacoustically Motivated Binaural Noise Reduction and Cue Preservation Techniques. PhD thesis, Carl von Ossietzky Universität Oldenburg, 2015.

[4] T. Gerkmann and R. C. Hendriks. Unbiased MMSE-Based Noise Power Estimation With Low Complexity and Low Tracking Delay. IEEE Transactions on Audio, Speech, and Language Processing, 20(4):1383–1393, May 2012.