Comparison of RTF Estimation Methods between a Head-Mounted Binaural Hearing Device and an External Microphone

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Motivation

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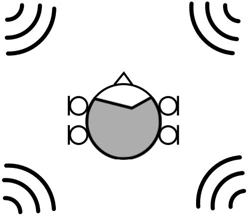
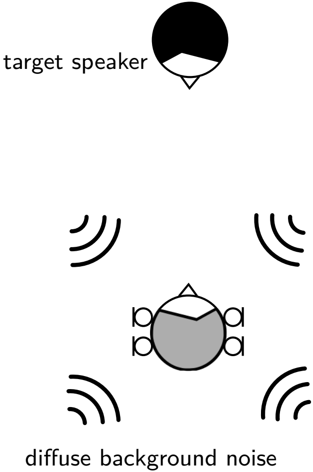
- Improve speech intelligibility in noisy scenarios



diffuse background noise

Motivation

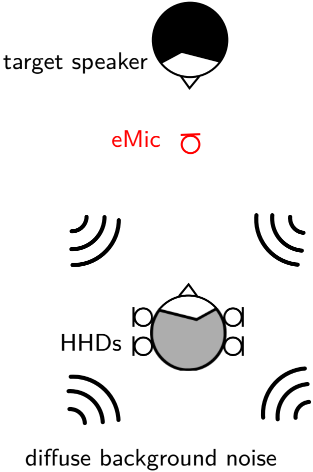
- Improve speech intelligibility in noisy scenarios
- Preserve binaural cues to assure spatial awareness



Motivation

- Improve speech intelligibility in noisy scenarios
- Preserve binaural cues to assure spatial awareness
- Adding an **external microphone** (eMic) to **head-mounted hearing devices** (HHDs) improves algorithm performance

[Szurley2016], [Gößling2017]



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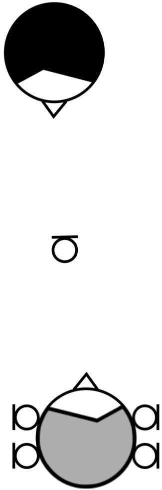

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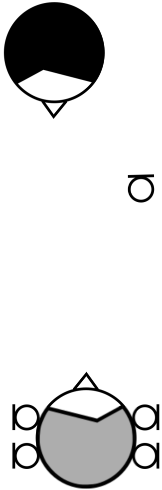

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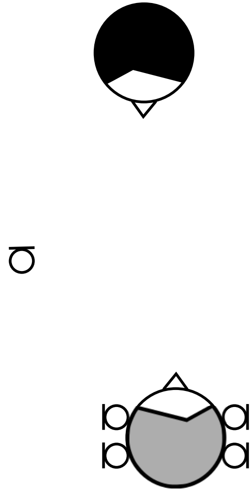

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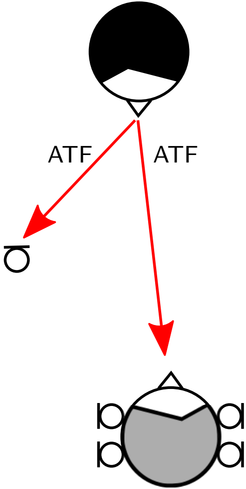
- Estimate the **acoustic transfer functions** (ATFs) or...



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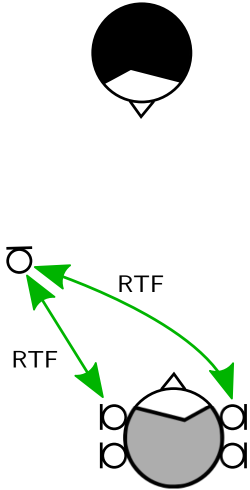
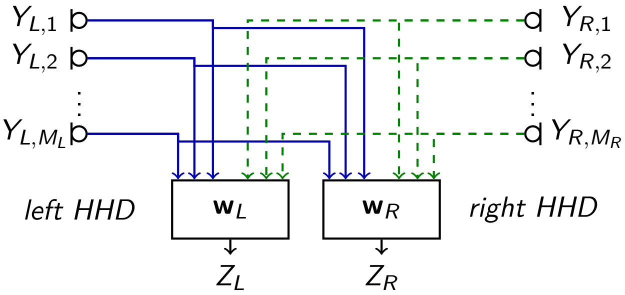
- Fixed beamforming is possible for head-mounted microphones
- **Position of eMic is unknown**
- Estimate the **acoustic transfer functions** (ATFs) or...
- ... estimate the **relative transfer functions** (RTFs) between eMic and HHDs



Binaural Noise Reduction

Extended Binaural Noise Reduction System



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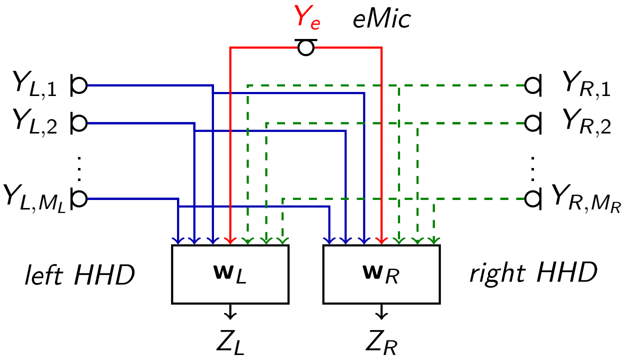

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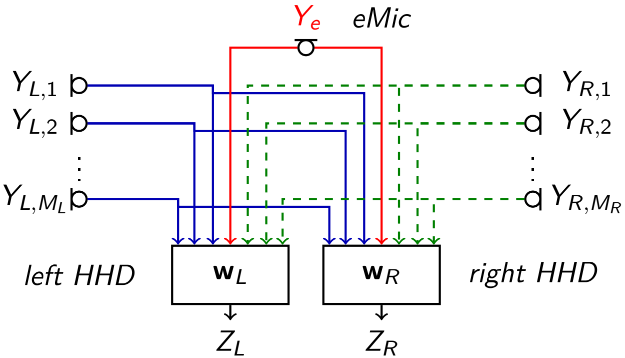

Input signal vector:
$\mathbf{y}(k,l) = \mathbf{x}(k,l) + \mathbf{n}(k,l)$

Single speech source:
$\mathbf{x}(k,l) = \mathbf{a}(k,l)S(k,l)$

Relative Transfer Functions (RTFs)

The relative transfer function (RTF) vectors, relating the ATF vector to the reference microphones, are defined as:

$$\mathbf{h}_L = \frac{\mathbf{a}}{A_L} = \left[1,\ \frac{A_{L,2}}{A_L},\ \ldots,\ \frac{A_{L,M_L}}{A_L},\ \frac{A_{R,1}}{A_L},\ \ldots,\ \frac{A_{R,M_R}}{A_L},\ \frac{A_e}{A_L}\right]^T$$

$$\mathbf{h}_R = \frac{\mathbf{a}}{A_R} = \left[\frac{A_{L,1}}{A_R},\ \ldots,\ \frac{A_{L,M_L}}{A_R},\ 1,\ \frac{A_{R,2}}{A_R},\ \ldots,\ \frac{A_{R,M_R}}{A_R},\ \frac{A_e}{A_R}\right]^T$$

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Last entry relates the eMic to the (head-mounted) reference microphones and needs to be estimated

Binaural MVDR Beamforming

- Minimizing output noise power
- Preserving speech component in reference microphone signals

Optimization problem for left filter

$$\mathbf{w}_L = \arg\min_{\mathbf{w}} \mathcal{E}\left\{\left|\mathbf{w}^H\mathbf{n}\right|^2\right\} \quad \text{s.t.} \quad \mathbf{w}^H\mathbf{x} = X_L$$

Solution for left filter

$$\mathbf{w}_L = \frac{\mathbf{R}_n^{-1}\mathbf{a}}{\mathbf{a}^H\mathbf{R}_n^{-1}\mathbf{a}} A_L^* = \frac{\mathbf{R}_n^{-1}\mathbf{h}_L}{\mathbf{h}_L^H\mathbf{R}_n^{-1}\mathbf{h}_L}$$

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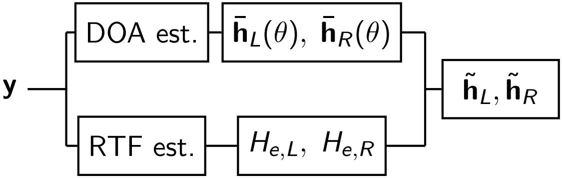
ATFs are not required to steer the beamformer!

RTF estimation methods

RTF vector construction

- **Fixed beamforming** for head-mounted microphones, e.g, based on direction-of-arrival θ (DOA) estimation
- RTFs can be measured or simulated in advance
- Not possible for eMic $\Rightarrow$ **RTF estimation is needed**



RTF estimation methods

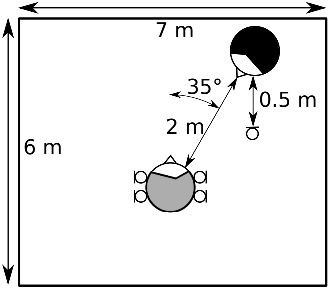
Ground truth:

$$\boxed{H_{e,L} = \frac{\mathbf{e}_e^T \mathbf{R}_x \mathbf{e}_L}{\mathbf{e}_L^T \mathbf{R}_x \mathbf{e}_L} = \frac{A_e}{A_L}}$$

- Biased approach: $H_{e,L}^{\mathrm{b}} = \frac{\mathbf{e}_e^T \mathbf{R}_y \mathbf{e}_L}{\mathbf{e}_L^T \mathbf{R}_y \mathbf{e}_L}$
- MVDR pre-processing approach: $H_{e,L}^{\mathrm{pp}} = \frac{\mathbf{e}_e^T \mathbf{R}_y \mathbf{w}_{\mathrm{H},L}}{\mathbf{w}_{\mathrm{H},L}^H \mathbf{R}_y \mathbf{w}_{\mathrm{H},L}}$
- Covariance whitening approach: $H_{e,L}^{\mathrm{cw}} = \frac{\mathbf{e}_e^T \mathbf{R}_n^{1/2} \mathbf{v}_{\max}}{\mathbf{e}_L^T \mathbf{R}_n^{1/2} \mathbf{v}_{\max}}$

Experimental results

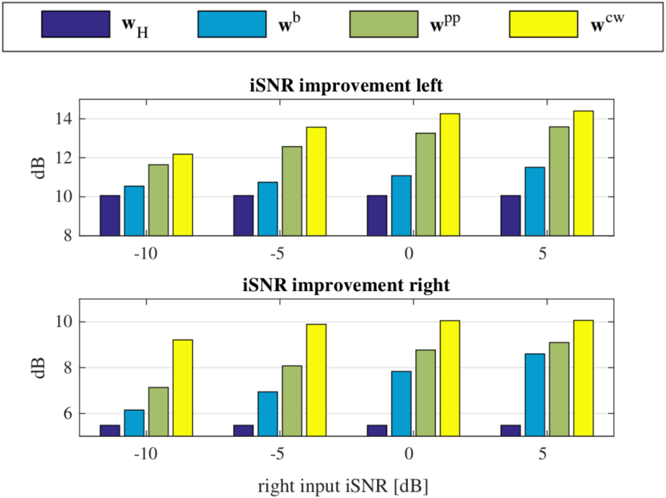
Experimental setup



- Male target speaker
- Diffuse babble noise
- $M_L = M_R = 2$
- T60 = 350 ms
- 16 kHz @ 16 ms (50% OL)

- Assuming $\theta = 35^\circ$
- $\mathbf{R}_n$ estimation during 2 s noise-only initialization
- $\mathbf{R}_y$ estimation during 18 s speech-plus-noise
- Batch filtering

Experimental results



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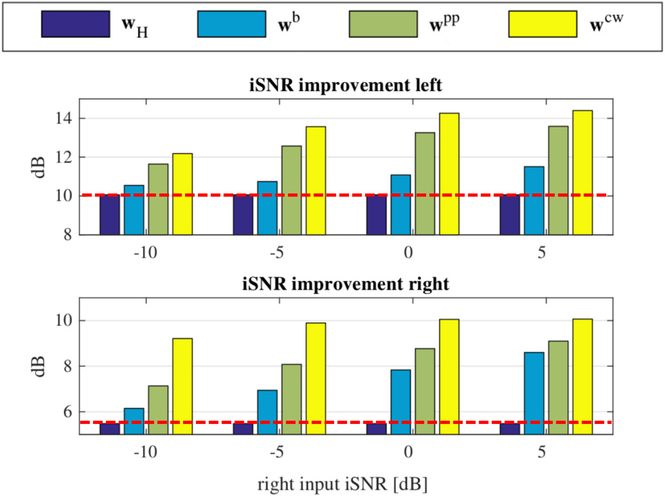

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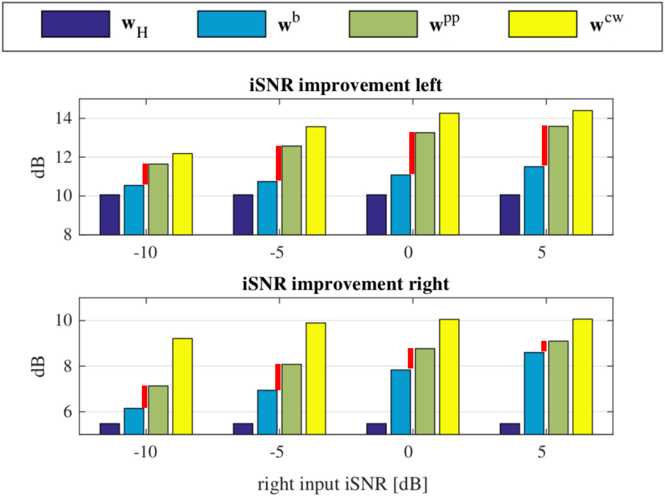

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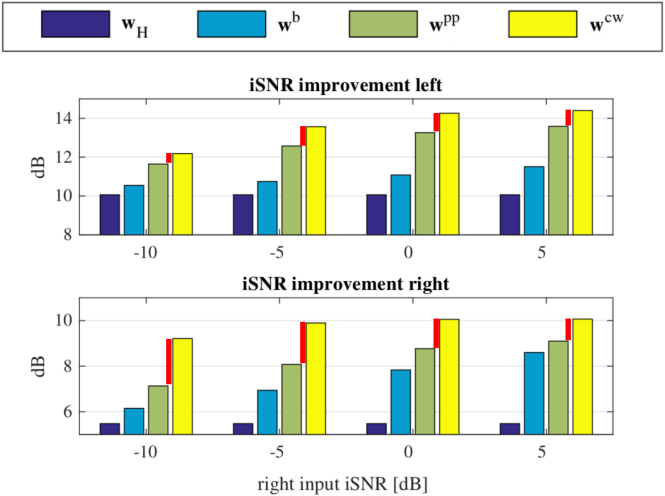

Conclusion and Outlook

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1. It is possible to estimate RTFs and incorporate an eMic into a binaural MVDR beamformer in an experimental scenario based on real-world signals
2. Pre-processing proved beneficial compared to baised approach
3. Covariance whitening outperformed the other approaches

Outlook:

1. Directional noise sources (extended BLCMV beamformer)
2. Practical problems, e.g. synchronization (influence of clock drift/offset), online implementations and dynamic scenarios

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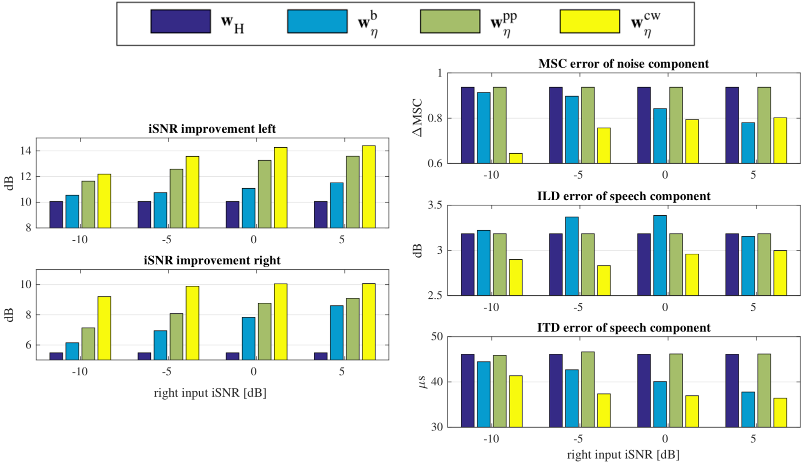
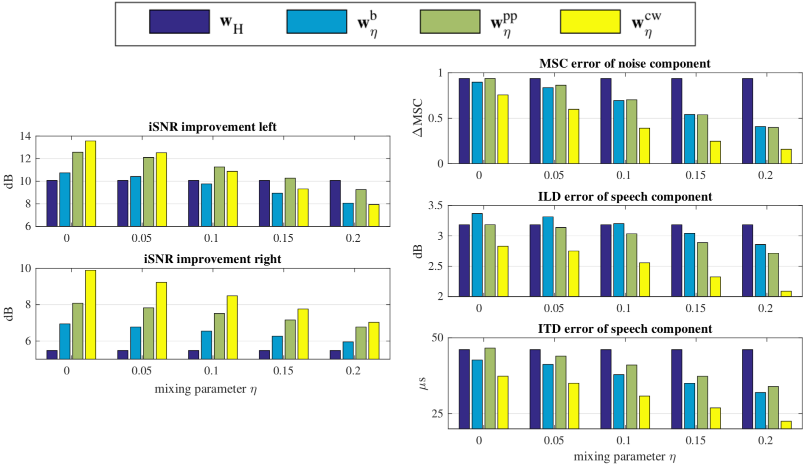
Thanks for your attention!


$\mathbf{w}_H$
$\mathbf{w}_\eta^b$
$\mathbf{w}_\eta^{pp}$
$\mathbf{w}_\eta^{cw}$
iSNR improvement left
dB
14
12
10
8
-10
-5
0
5
iSNR improvement right
dB
10
8
6
right input iSNR [dB]
MSC error of noise component
ΔMSC
1
0.8
0.6
ILD error of speech component
3.5
3
2.5
ITD error of speech component
μs
50
40
30
right input iSNR [dB]


$\mathbf{w}_H$
$\mathbf{w}_\eta^b$
$\mathbf{w}_\eta^{pp}$
$\mathbf{w}_\eta^{cw}$
iSNR improvement left
dB
14
12
10
8
6
0
0.05
0.1
0.15
0.2
iSNR improvement right
dB
10
8
6
mixing parameter η
MSC error of noise component
Δ MSC
1
0.5
0
ILD error of speech component
dB
3.5
3
2.5
2
ITD error of speech component
μs
50
25
mixing parameter η