AASP5-P5.5

Sound Field Interpolation for Rotation-Invariant Multichannel Array Signal Processing

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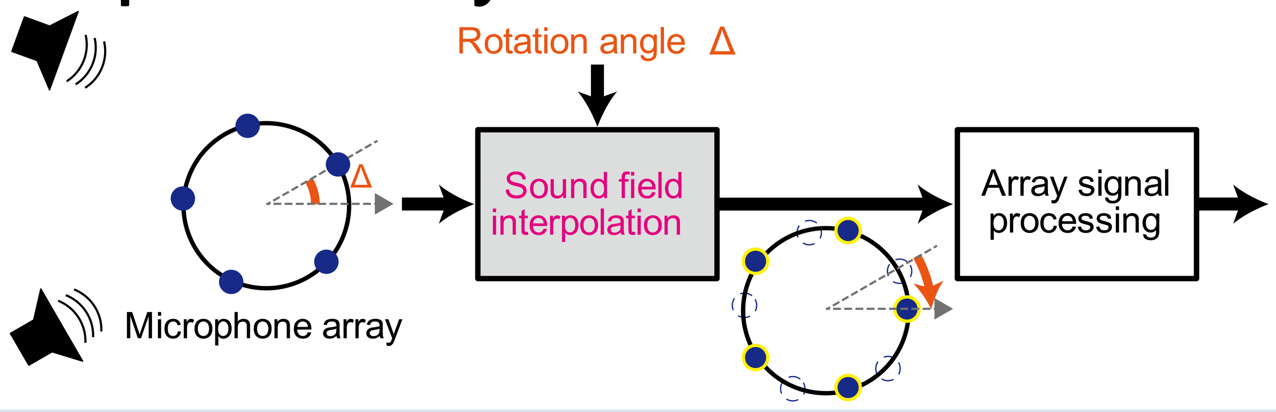
URL of the paper

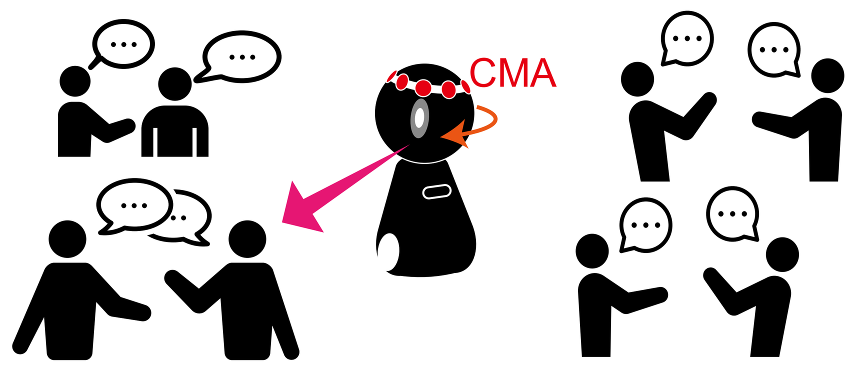
Abstract

- This study addresses sound field interpolation (SFI) for array signal processing (ASP)
  - **Robust to acoustic transfer system (ATS) variation due to the microphone array's rotation.**
  - **Highly versatile to downstream ASP.**
- Technical points:
  - **Sound field periodicity on circumference**
  - **Noninteger sample shift**



Introduction

- Background
  - ASP assumes a time-invariant ATS, but it is a **time-variant** one actually.
  - ATS's variation forces the re-estimation of spatial information, e.g., covariance. ⇒ makes online processing difficult.
- Motivation
  - We want to follow the ATS's variation caused by rotating circular microphone array (CMA).
  - We want to apply SFI to existing ASP methods.



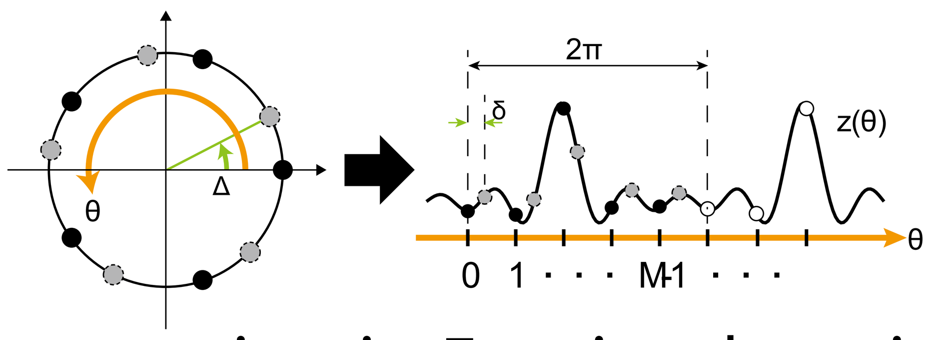
Situation

SFI method

- Idea: Estimating the signal at the position where no microphone exists by SFI on circumference
- Key: Observation by Δ-rotated CMA = δ-shifted z

$\Delta = 2\pi\delta/M$

M # of mics



- Formulation
  - Sample shift=phase rotation in Fourier domain

$$z_m(\delta) = \mathscr{F}_{\mathrm{D}}^{-1}\left[\mathscr{F}_{\mathrm{D}}\left[z_m\right] e^{j\Delta k}\right] = \sum_{n=0}^{M-1} z_n U_{mn}(\delta),\ m=0,\ldots,M-1$$

DFT

$$U_{mn}(\delta) = \begin{cases} \frac{1-(-1)^{n-m}e^{-j\delta\pi}}{M} + \frac{\operatorname{sinc}(ML)\cos(M+2)L\pi}{\operatorname{sinc}(2L)}, & (\text{even } M), \\ \frac{1}{M} + \frac{M-1}{M}\frac{\operatorname{sinc}\left((M-1)L\right)\cos(M+1)L\pi}{\operatorname{sinc}(2L)}, & (\text{odd } M). \end{cases}$$

$L=(n-m-\delta)/2M$

  - Matrix representation

$$\boldsymbol{z}(\delta) = \boldsymbol{U}(\Delta)\boldsymbol{z},\quad \boldsymbol{U}(\Delta) = \left(U_{mn}(\delta)\right).\quad \boldsymbol{z} \in \mathbb{C}^M$$

* This method is similar to circular harmonics domain processing.

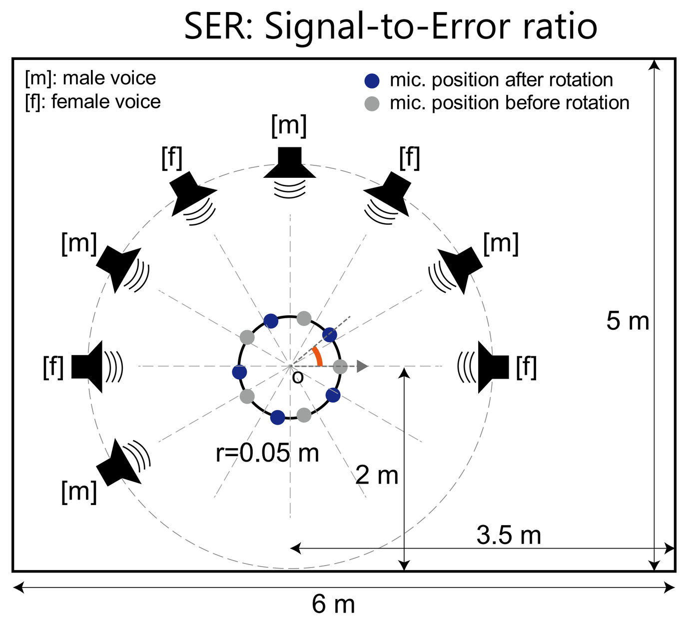
Applying SFI to ASP

- Raising the beamforming task as an example
  - Let $\boldsymbol{x}_{tf}$ be the STFT-domain observations $\boldsymbol{x}_{tf} = \left[x_{0tf} \ \cdots \ x_{(M-1)tf}\right]^{\mathsf{T}}$
  - Pre-estimating spatial filter $\boldsymbol{w}_f$ at the reference position (= no rotation)
  - Estimating the reference observation = SFI along the inverse rotation $\hat{\boldsymbol{x}}_{\mathrm{ref},tf} = \boldsymbol{U}(-\theta_t)\boldsymbol{x}_{tf}$
  - Filtering with pre-estimated filter $y_{tf} = \boldsymbol{w}_f^{\mathsf{H}}\hat{\boldsymbol{x}}_{\mathrm{ref},tf}$
- SFI enables the time-variant ATS to be regarded virtually as a **time-invariant** ATS.
- SFI can be applied to various ASP, e.g.,
  - Self-rotation localization with SFI [Lian+ APSIPA ASC 2020]
  - SFI with unequally spaced CMA [Luan+ EUSIPCO 2022, 2023]
  - BSS with SFI [Nakashima+ APSIPA Trans. on SIP] (Open Access)

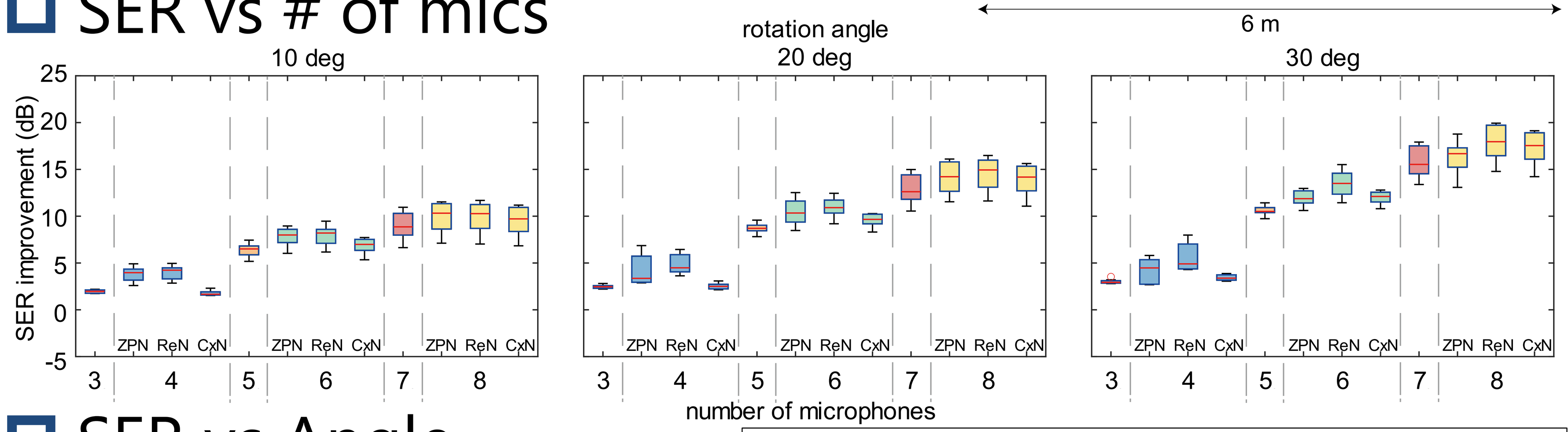
Evaluation

RTF: Relative transfer function
SER: Signal-to-Error ratio

- Setup
  - Mixture: 2 srcs, fs=16 kHz RT60≈100 ms, 12 envs,
  - STFT: 1/8 shifts, 64 ms Hamming window
  - BF: MPDR + RTF

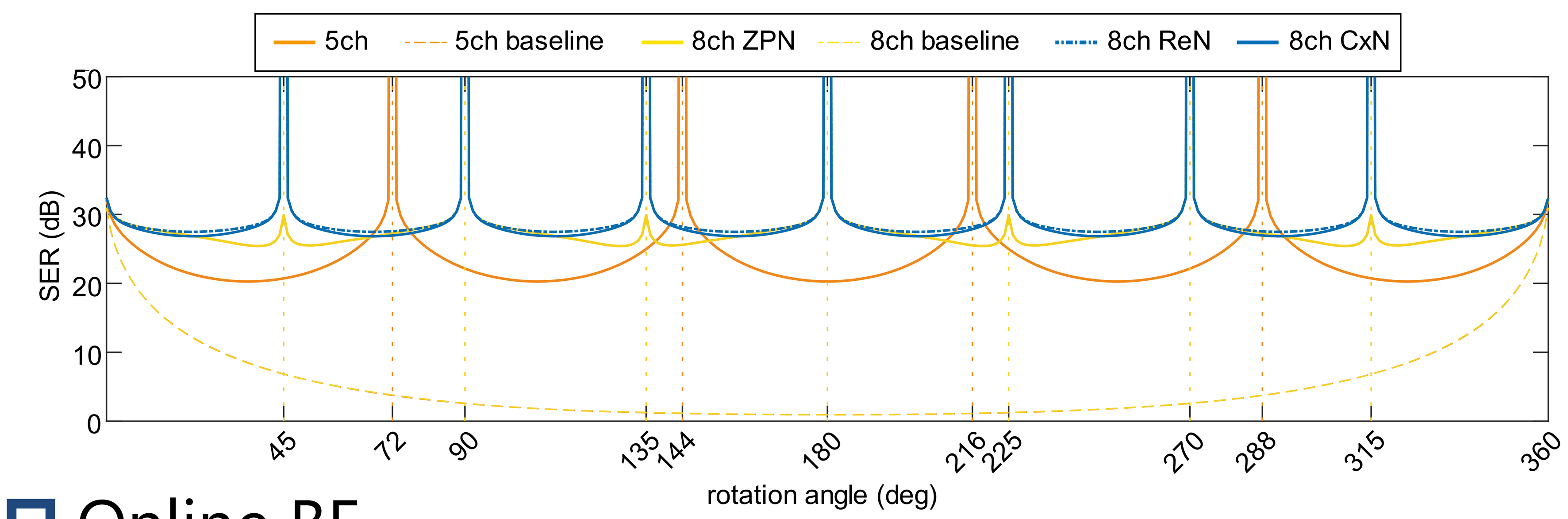


- SER vs # of mics

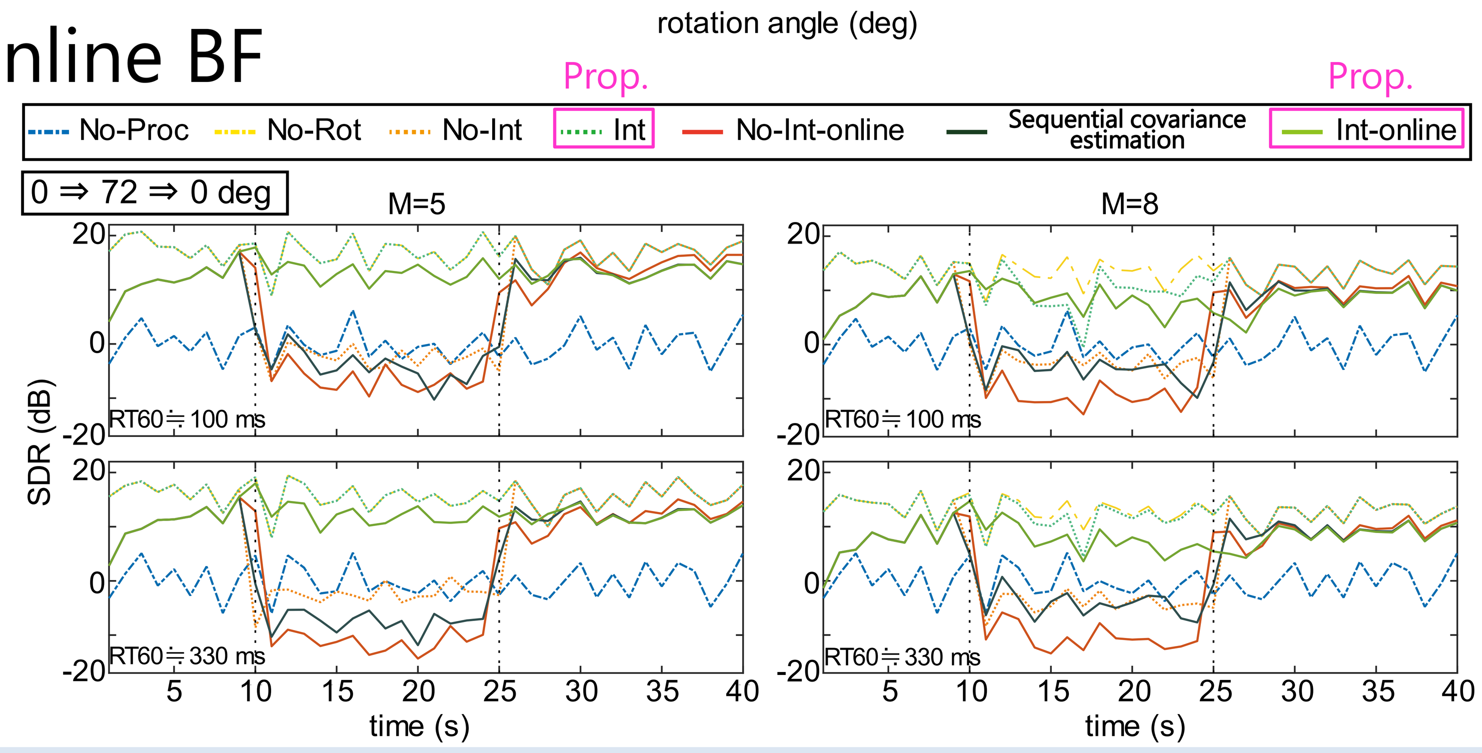


Note that ZPN, Ren, and CxN are other versions of SFI.

- SER vs Angle



- Online BF



Conclusion

- SFI and BF achieved quick response online beamforming even when the CMA rotates.
- Future work includes improving the estimation accuracy of the higher frequency component and applying different ASP methods.