Fast Online Source Steering Algorithm for Tracking Single Moving Source using Online Independent Vector Analysis

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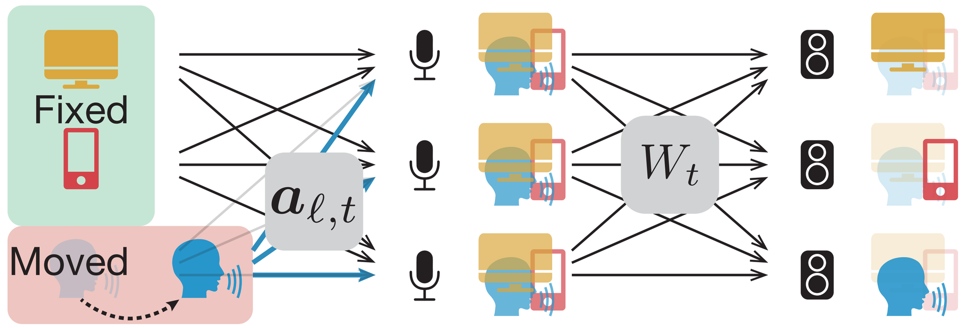
Overview

Single source tracking (1-ST)



- BSS under situations where ***only one*** source moves

Fast online algorithm for 1-ST

Conventional methods

- Online IP [Taniguchi+2014]
  - Must update **all demixing vectors**
  - Not suitable for 1-ST
- Online ISS [Nakashima+2022]
  - Can directly update $a_{\ell,t}$
  - Suitable for 1-ST ***yet not optimal***

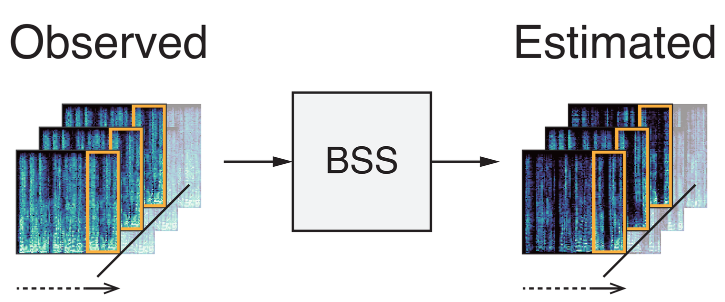
Contribution

Method		Complexity for 1-ST* $y_t = W_t x_t$	Optimize W_t	
Batch (*per freq.)	Optimal	$O(K^2T)$	$O(KT)$	Parameter: $a_\ell \in \mathbb{C}^K$ with $y_1, \ldots, y_T$
	IP	$O(K^2T)$	$O(K^3T)$	
	ISS	$O(K^2T)$	$O(KT)$	Optimal
Online (*per frame/freq.)	Optimal	$O(K^2)$	$O(K)$	Parameter: $a_{\ell,t} \in \mathbb{C}^K$
	IP	$O(K^2)$	$O(K^3)$	
	ISS	$O(K^2)$	$O(K^3)$	Not optimal...
Proposed	OSS†	$O(K^2)$	$O(K^2)$	Faster than Online ISS
	FastOSS	$O(K^2)$	$O(K)$	Optimal

† online source steering
⋆ K, T: # of sources/frames
ℓ: target source index

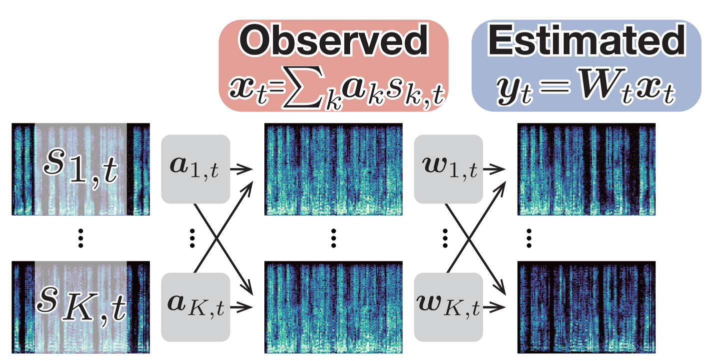
Background

Online Blind source separation (BSS)



- BSS using past/current data
- Necessary for real-time app.
- Popular methods:
  - Online IVA [Kim2010]
  - **Online AuxIVA** [Taniguchi+2014]

Online AuxIVA



- Optimization problem

$$\min. \sum_k w_{k,t}^{\mathsf{H}} V_{k,t} w_{k,t} - \log|\det W_t|^2$$

Parameter

Covariance update

$$V_{k,t} \leftarrow \alpha V_{k,t-1} + (1-\alpha)\varphi(r_{k,t}) x_t x_t^{\mathsf{H}}$$

Forgetting factor, Prev. cov., Weight, Current obs.

Optimization of W_t for batch AuxIVA directly applicable
- Iterative projection (IP) [Ono2011]
- Iterative source steering (ISS) [Scheibler+2020]

Conventional and Proposed Methods

Online ISS Conventional

$\hat{y}_t \leftarrow W_{t-1} x_t$ // "Predict" estimated sources
for $k = 1, \ldots, K$
 $r_{k,t} \leftarrow \sqrt{\Sigma_f |\hat{y}_{k,f,t}|^2}$ // Update "weight"
 $V_{k,t} \leftarrow \alpha V_{k,t-1} + (1-\alpha)\varphi(r_{k,t}) x_t x_t^{\mathsf{H}}$ // Update covariance
forall $k \neq \ell$ // Update "non-target" $w_{k,t}$
 $g_{k,t} \leftarrow w_{\ell,t-1}^{\mathsf{H}} V_{k,t} w_{k,t-1}$
 $G_{k,t} \leftarrow w_{\ell,t-1}^{\mathsf{H}} V_{k,t} w_{\ell,t-1}$
 $w_{k,t} \leftarrow w_{k,t-1} - \frac{g_{k,t}}{G_{k,t}} w_{\ell,t-1}$
$G_{\ell,t} \leftarrow w_{\ell,t-1}^{\mathsf{H}} V_{\ell,t} w_{\ell,t-1}$ // Update "target" $w_{\ell,t}$
$w_{\ell,t} \leftarrow G_{\ell,t}^{-1/2} w_{\ell,t-1}$
$y_t \leftarrow W_t x_t$ // Update estimated sources

Calc. $V_{k,t}, g_{k,t}, G_{k,t}$: $O(K^2)$ for each k ➞ $O(K^3)$ **in total**

Construct recursive formulae for $g_{k,t}, G_{k,t}$ to avoid $V_{k,t}$

Derivation of OSS

$$g_{k,t} = w_{\ell,t-1}^{\mathsf{H}} V_{k,t} w_{k,t-1} = w_{\ell,t-1}^{\mathsf{H}} \left(\alpha V_{k,t-1} + (1-\alpha)\varphi(r_{k,t}) x_t x_t^{\mathsf{H}}\right) w_{k,t-1}$$
$$= \alpha w_{\ell,t-1}^{\mathsf{H}} V_{k,t-1} w_{k,t-1} + (1-\alpha)\varphi(r_{k,t})(w_{\ell,t-1}^{\mathsf{H}} x_t)(x_t^{\mathsf{H}} w_{k,t-1})$$
$\to 0$, $:= \hat{y}_{\ell,t}$, $:= \hat{y}_{k,t}^*$
$$= (1-\alpha)\varphi(r_{k,t})\hat{y}_{\ell,t}\hat{y}_{k,t}^* \quad O(1)$$

$$G_{k,t} = w_{\ell,t-1}^{\mathsf{H}} V_{k,t} w_{\ell,t-1} = w_{\ell,t-1}^{\mathsf{H}} \left(\alpha V_{k,t-1} + (1-\alpha)\varphi(r_{k,t}) x_t x_t^{\mathsf{H}}\right) w_{\ell,t-1}$$
$$= \alpha w_{\ell,t-1}^{\mathsf{H}} V_{k,t-1} w_{\ell,t-1} + (1-\alpha)\varphi(r_{k,t})(w_{\ell,t-1}^{\mathsf{H}} x_t)(x_t^{\mathsf{H}} w_{\ell,t-1})$$
$\to \frac{G_{k,t-1}}{G_{\ell,t-1}}$, $:= \hat{y}_{\ell,t}$, $:= \hat{y}_{\ell,t}^*$
$$= \alpha\frac{G_{k,t-1}}{G_{\ell,t-1}} + (1-\alpha)\varphi(r_{k,t})|\hat{y}_{\ell,t}|^2 \quad O(1)$$

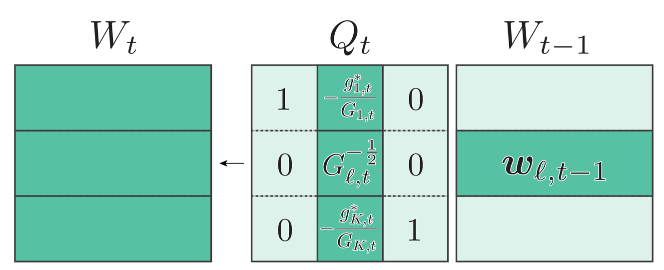
OSS Proposed

$\hat{y}_t \leftarrow W_{t-1} x_t$ // "Predict" estimated sources
for $k = 1, \ldots, K$
 $r_{k,t} \leftarrow \sqrt{\Sigma_f |\hat{y}_{k,f,t}|^2}$ // Update "weight"
 ~~$V_{k,t} \leftarrow \alpha V_{k,t-1} + (1-\alpha)\varphi(r_{k,t}) x_t x_t^{\mathsf{H}}$~~ // No covariance update!
forall $k \neq \ell$ // Update "non-target" $w_{k,t}$
 $g_{k,t} \leftarrow (1-\alpha)\varphi(r_{k,t})\hat{y}_{\ell,t}\hat{y}_{k,t}^*$
 $G_{k,t} \leftarrow \alpha\frac{G_{k,t-1}}{G_{\ell,t-1}} + (1-\alpha)\varphi(r_{k,t})|\hat{y}_{\ell,t}|^2$
 $w_{k,t} \leftarrow w_{k,t-1} - \frac{g_{k,t}}{G_{k,t}} w_{\ell,t-1}$
$G_{\ell,t} \leftarrow \alpha + (1-\alpha)\varphi(r_{\ell,t})|\hat{y}_{\ell,t}|^2$ // Update "target" $w_{\ell,t}$
$w_{\ell,t} \leftarrow G_{\ell,t}^{-1/2} w_{\ell,t-1}$
$y_t \leftarrow W_t x_t$ // Update estimated sources

FastOSS Proposed

OSS requires $O(K^2)$ to update $w_{k,t}$ for $k = 1, \ldots, K$

Redefinition of OSS by multiplicative update of W_t



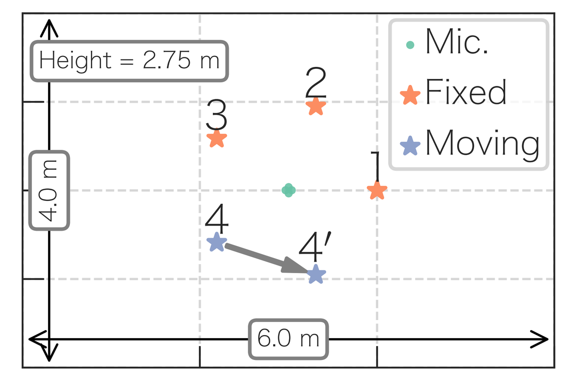
$$W_t = Q_t W_{t-1}$$
$$= Q_t(Q_{t-1} W_{t-2})$$
$$\vdots$$
$$= Q_t(Q_{t-1} \cdots Q_1) W_0 := \widetilde{Q}_t W_0$$

- Update one column of Q_t (K variables) ➞ Calculated $O(K)$

$Q_t \times Q_{t-1}$ is also $O(K)$ ➞ **Optimal cost!**

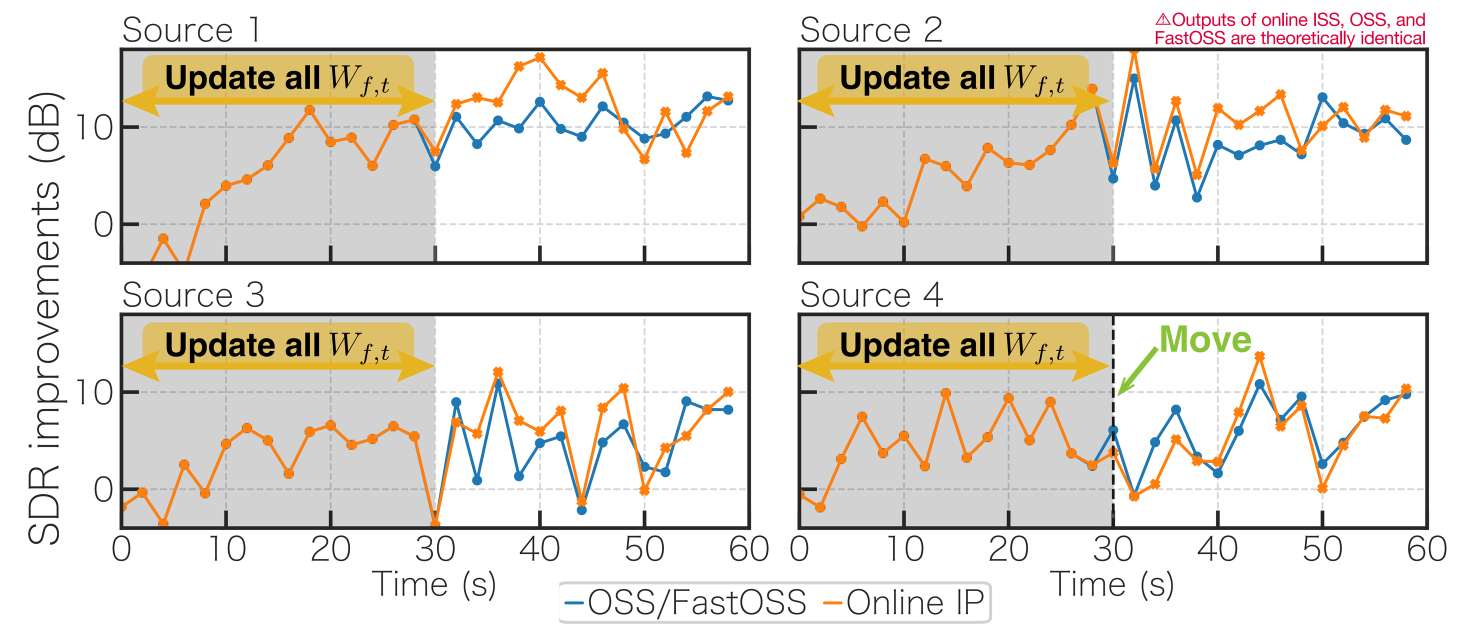
Experiments

Room layout



- 4 mic./sources
  - Source 4 moved instantaneously
  - The others were fixed
- RT_{60}: approx. 300 ms
- When/which source moved was given in an oracle manner

Separation performance

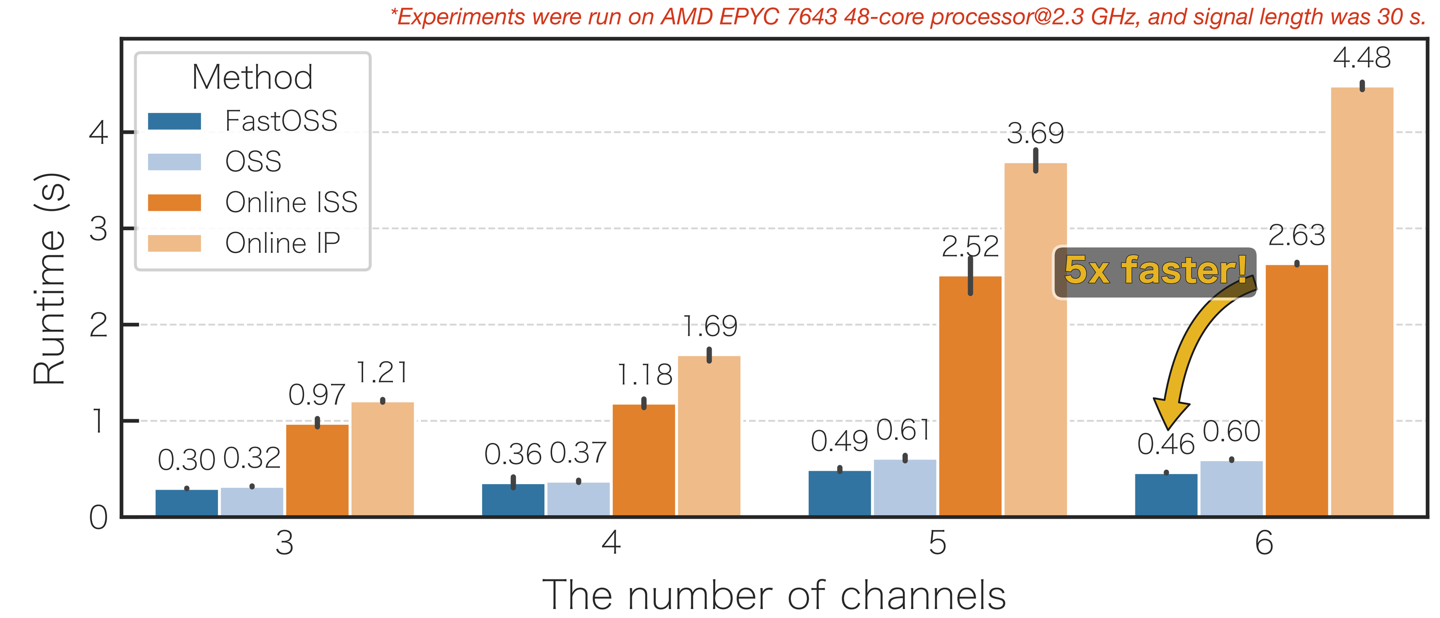


- Online IP updates K^2 parameters $(w_{1,t}, \ldots, w_{K,t})$
- Proposed OSS/FastOSS updates only K parameters $(a_{\ell,t})$

OSS/FastOSS performs as well as online IP

Runtime performance

*Experiments were run on AMD EPYC 7643 48-core processor@2.3 GHz, and signal length was 30 s.



FastOSS was **5x faster** than Online ISS for 6 channels

Conclusion

Summary

- **1-ST**: online BSS under a condition where *only one* source moves
- **OSS/FastOSS**
  - Fast online algorithm for 1-ST
  - FastOSS achieved optimal cost

Future work

- Real-time implementation/evaluation
- OSS for ***two source trakcking***

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