Imperial College London

Speech and Audio Processing Lab

Speech Dereverberation of a Polynomial EVD Subspace Approach

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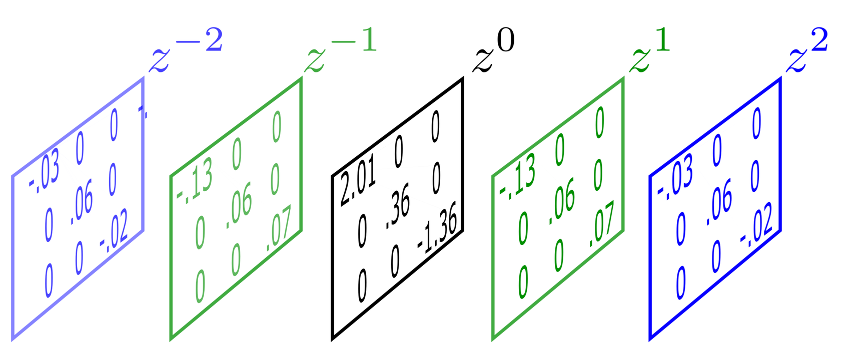
Summary

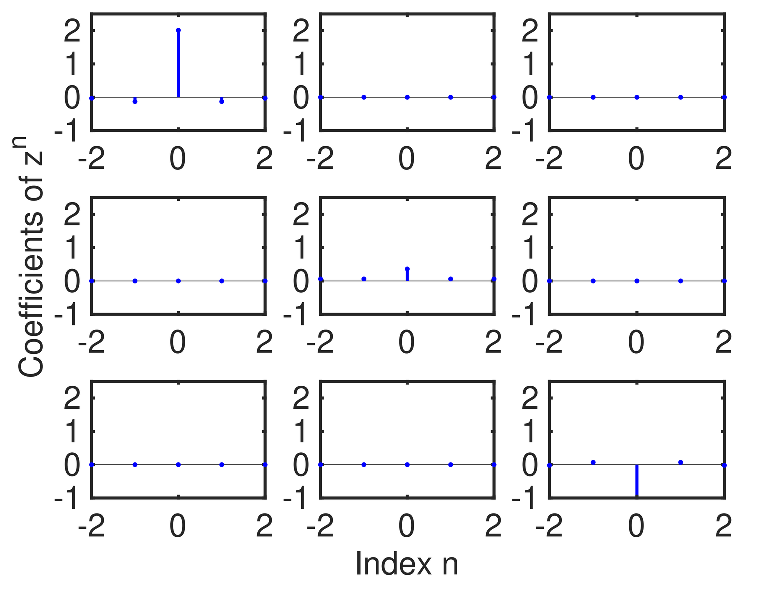
- PEVD-based speech enhancement algorithm [1], which is designed for noise reduction, is also effective for dereverberation
- PEVD algorithm retains the early and suppresses the late reflections
- Completely blind and unsupervised approach, no noise estimation
- No noticeable artifacts

What is a Polynomial Matrix?

Polynomial with matrix coefficients



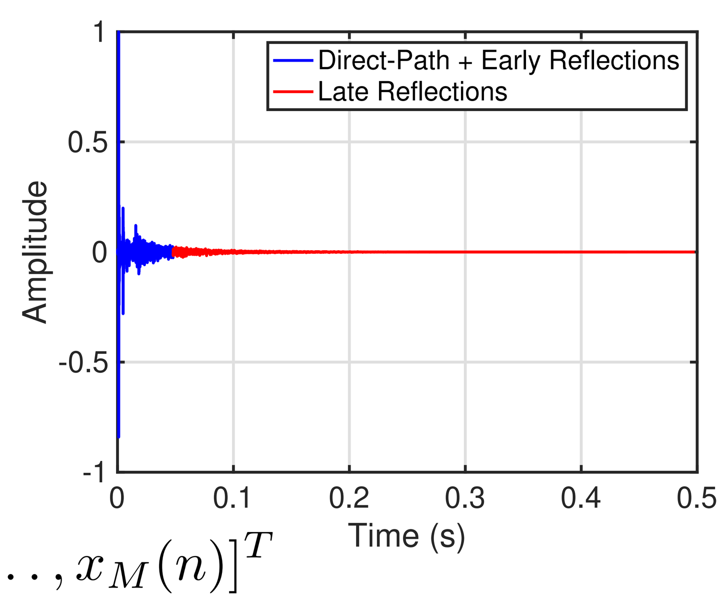
Matrix with polynomial elements



How do Polynomial Matrices Arise?

Multichannel Reverberant Signal Model:

$$x_m(n) = \mathbf{h}_m^T \mathbf{s}_0(n) + v_m(n) = \tilde{s}_m(n) + \tilde{v}_m(n)$$



From M Sensors:

$$\mathbf{x}(n) = [x_1(n), x_2(n), \ldots, x_M(n)]^T$$

Space-time Covariance Matrix, assuming stationarity, is:

$$\mathbf{R}_{\mathbf{xx}}(\tau) = \mathbb{E}[\mathbf{x}(n)\mathbf{x}^H(n-\tau)]$$

Para-Hermitian Polynomial Matrix:

$$\boldsymbol{\mathcal{R}}_{\mathbf{xx}}(z) = \sum_{\tau=-W}^{W} \mathbf{R}_{\mathbf{xx}}(\tau) z^{-\tau}$$

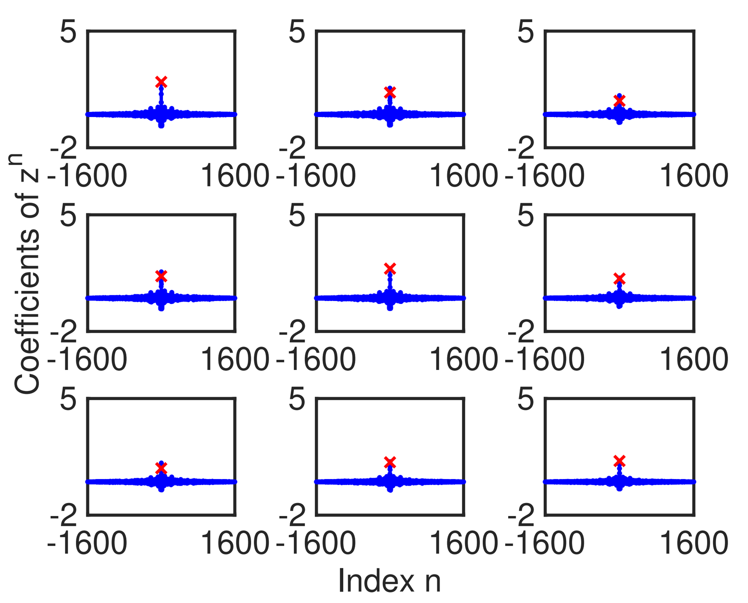
Polynomial Eigenvalue Decomposition (PEVD)

The PEVD of $\boldsymbol{\mathcal{R}}_{\mathbf{xx}}(z)$ is [2]:

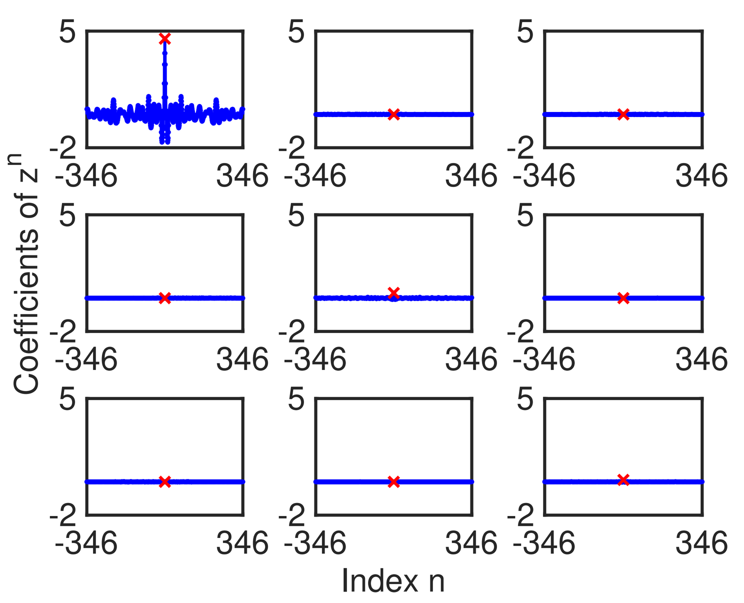
$$\boldsymbol{\mathcal{R}}_{\mathbf{xx}}(z) \approx \boldsymbol{\mathcal{U}}^P(z)\boldsymbol{\Lambda}(z)\boldsymbol{\mathcal{U}}(z) = \left[\ \boldsymbol{\mathcal{U}}_{\tilde{s}}^P(z) \mid \boldsymbol{\mathcal{U}}_{\tilde{v}}^P(z)\ \right] \begin{bmatrix} \boldsymbol{\Lambda}_{\tilde{s}}(z) & \mathbf{0} \\ \mathbf{0} & \boldsymbol{\Lambda}_{\tilde{v}}(z) \end{bmatrix} \begin{bmatrix} \boldsymbol{\mathcal{U}}_{\tilde{s}}(z) \\ \boldsymbol{\mathcal{U}}_{\tilde{v}}(z) \end{bmatrix}$$

with orthogonal signal, $\{\cdot\}_{\tilde{s}}$ and noise subspaces, $\{\cdot\}_{\tilde{v}}$.

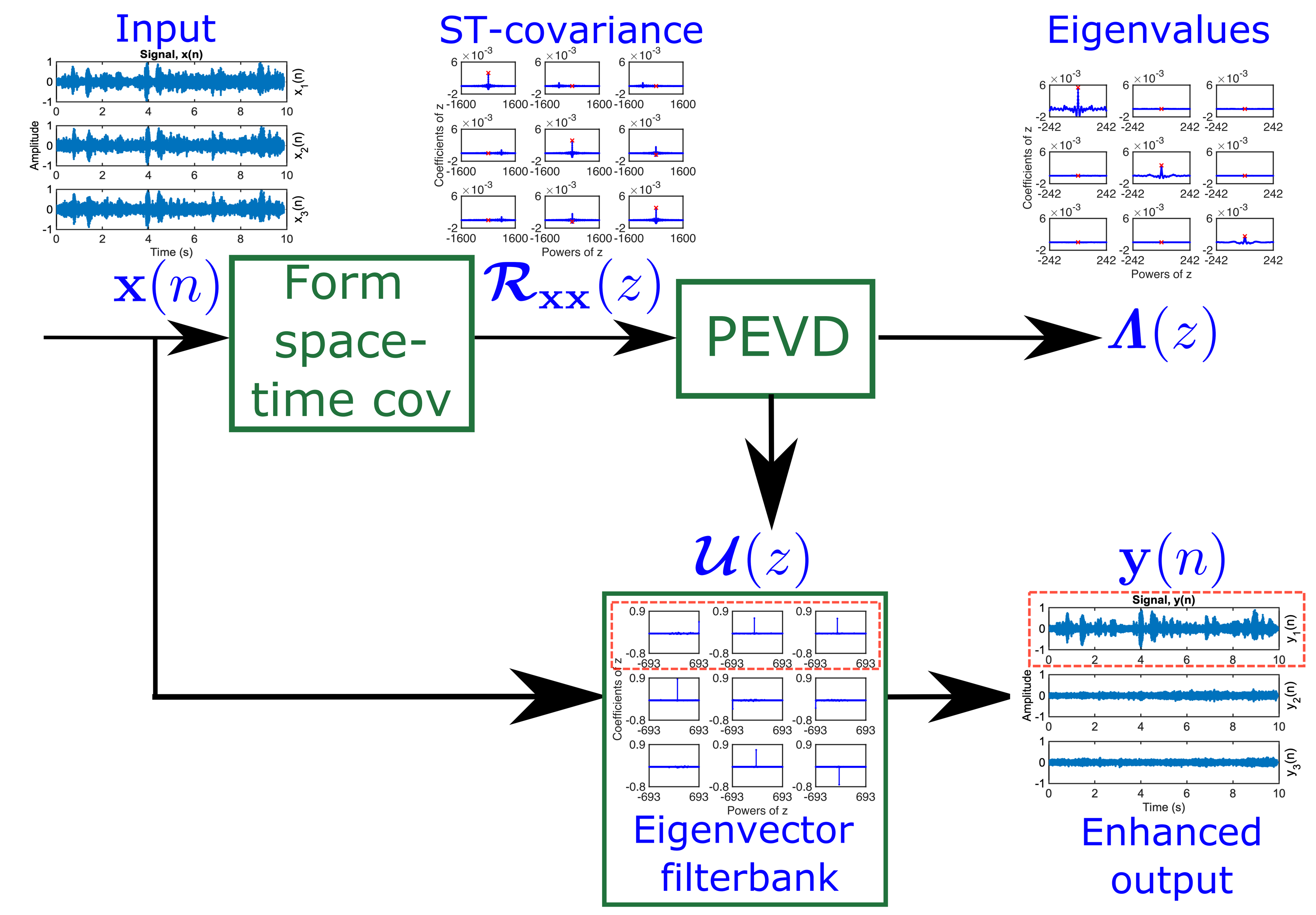
$\boldsymbol{\mathcal{R}}_{\mathbf{xx}}(z)$ Example



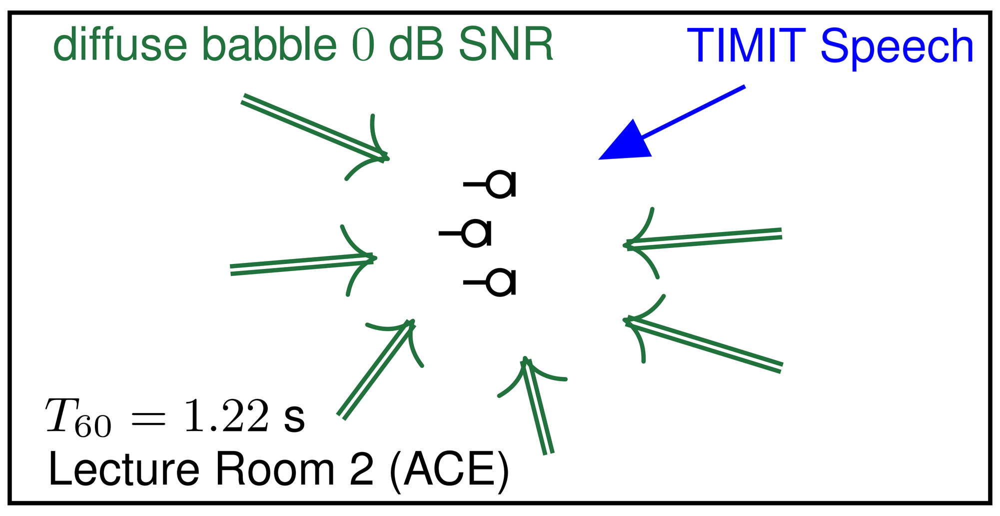
Eigenvalue, $\boldsymbol{\Lambda}(z)$



PEVD-based Speech Enhancement Algorithm [1]



Experiment Setup: Reverberant Speech in Noise



Comparative Algorithms

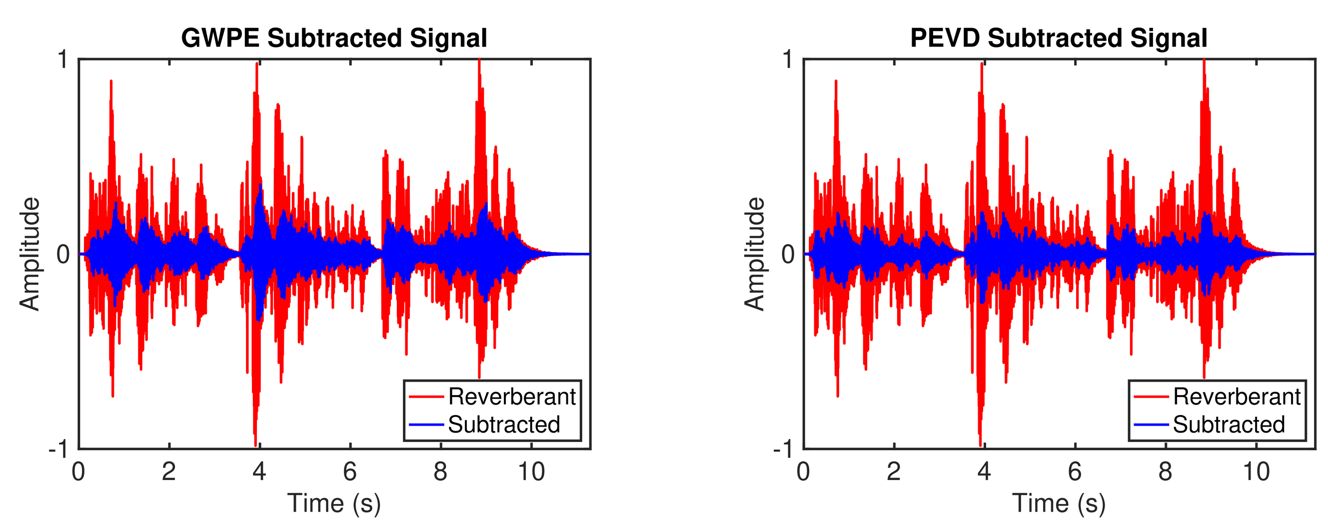
1. Generalized Weighted Prediction Error (GWPE)
2. Multichannel Subspace (MCSUB) - Uses an EVD
3. Oracle Multichannel Wiener Filter (OMWF) - Given clean speech

Evaluation Measures

- Normalized Signal to Reverberant Ratio (NSRR)
- Bark Spectral Distortion (BSD)
- Frequency-weighted Segmental SNR (FwSegSNR)
- Perceptual Evaluation of Speech Quality (PESQ)

Simulation Results

Comparison of GWPE and PEVD processing in noise-free Lecture Room 2:



Dereverberation Performance for 0 dB Babble Noise in Lecture Room 2:

Algorithm	ΔNSRR	ΔBSD	ΔFwSegSNR	ΔPESQ
GWPE	0.22 dB	-0.12 dB	0.28 dB	0.05
MCSUB	-3.29 dB	0.21 dB	0.64 dB	0.21
OMWF	0.26 dB	-0.25 dB	3.12 dB	**0.29**
PEVD	**5.38 dB**	**-0.52 dB**	**3.56 dB**	0.20

Listening examples are available at [3].

References

[1] V. W. Neo, C. Evers, and P. A. Naylor, "PEVD-based speech enhancement in reverberant environments," in *Proc. IEEE ICASSP*, 2020, pp. 186–190.

[2] J. G. McWhirter, P. D. Baxter, T. Cooper, S. Redif, and J. Foster, "An EVD algorithm for para-Hermitian polynomial matrices," *IEEE Trans. Signal Process.*, vol. 55, no. 5, pp. 2158–2169, May 2007.

[3] V. W. Neo, C. Evers, and P. A. Naylor, *Speech dereverberation of a polynomial-EVD subspace approach*, Aug. 2020. [Online]. Available: `https://www.commsp.ee.ic.ac.uk/~sap/pevddrb` (visited on 01/01/2021).