# Model-based Spectral Reconstruction of Interferometric Acquisitions (poster)

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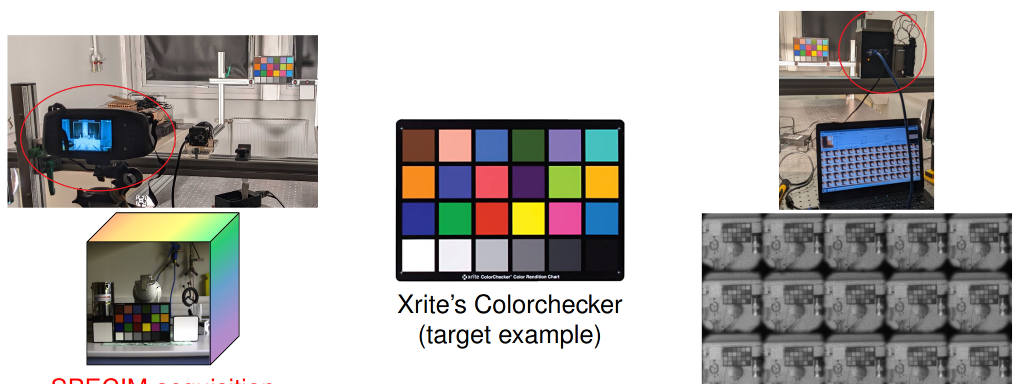
## Context

- Spectral information of the scene can be reconstructed from interferometric observations
- A simple inversion is not straightforward, and the *data is scarce*, but we have a good *knowledge* of the system
- We propose to use Loris-Verhoeven algorithm, a *model-based iterative* algorithm, with proximal solvers

### Examples of data acquisition sources

- Devices: Spectrometers and Interferometers
- Datasets: Real and Simulated
- Example targets: Colorchecker, Solar, Monochromatic



SPECIM acquisition (spectral, reference)

Xrite's Colorchecker (target example)

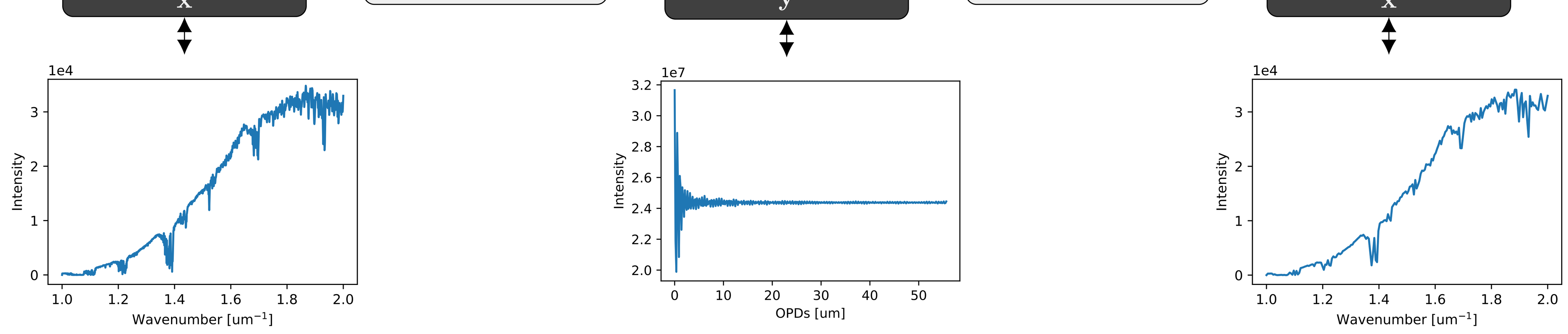
ImSPOC acquisition (interferometric, observations)

## Problem Statement

### Acquisition and Inversion Pipelines

- Direct model: $\mathbf{y} = \mathbf{A}\mathbf{x} + \mathbf{e}$, where
  - $\mathbf{x} \in \mathbb{R}^K$ (unknown) is the spectral radiance
  - $\mathbf{y} \in \mathbb{R}^L$ (observed) is the sampled interferogram
  - $\mathbf{A} \in \mathbb{R}^{L \times K}$ is the domain transfer matrix from that of $\mathbf{x}$ to that of $\mathbf{y}$
  - $\mathbf{e} \in \mathbb{R}^L$ is the noise, which we assume to be Gaussian
- The interferogram can be interpreted as a Fourier transformation of the spectrum.
- Goal: Estimate the value of $\mathbf{x}$ such that $\hat{\mathbf{x}} = \operatorname{argmin}_{\mathbf{x}} \frac{1}{2}\|\mathbf{y} - \mathbf{A}\mathbf{x}\|_2^2 + r(\mathbf{x})$

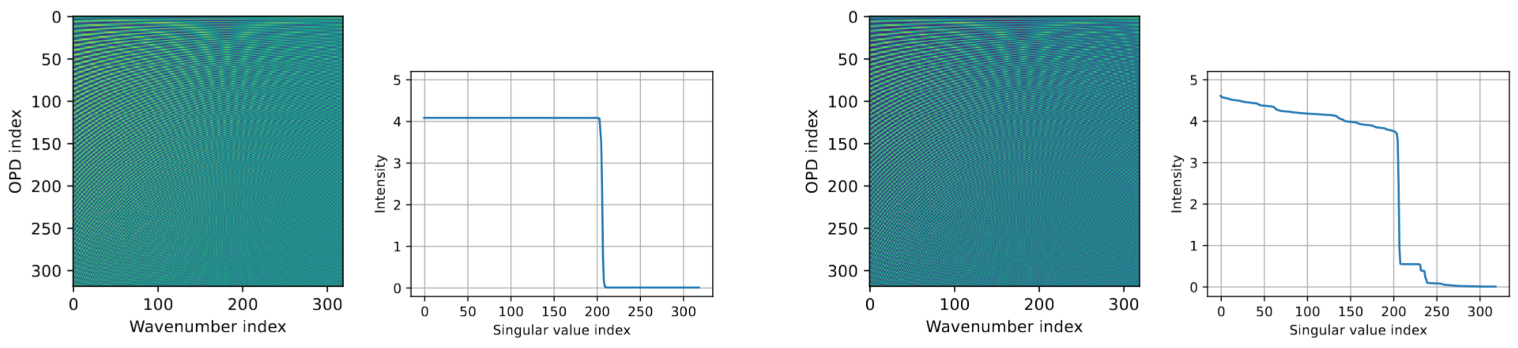
Continuous spectrum $\mathbf{x}$ → Acquisition model $\mathbf{A}(\cdot)$ → Observed interferogram $\mathbf{y}$ → Inversion protocol $\mathbf{A}^{(-1)}(\cdot)$ → Reconstructed spectrum $\hat{\mathbf{x}}$




## Spectral Formation

### Analytical Knowledge of the Transfer Matrix

- **Theoretical:** based on the number of emerging waves in the interferometer[1]:
  - 2-wave model (e.g., Michelson interferometers)
  - $\infty$-wave model (i.e., Airy's distribution, Fabry-Pérot etalons)
- **Real:** Characterized from monochromatic acquisitions of a real device[2]




2-wave model transfer matrix

$\infty$-wave model transfer matrix

## Methodology (Model-based methods)

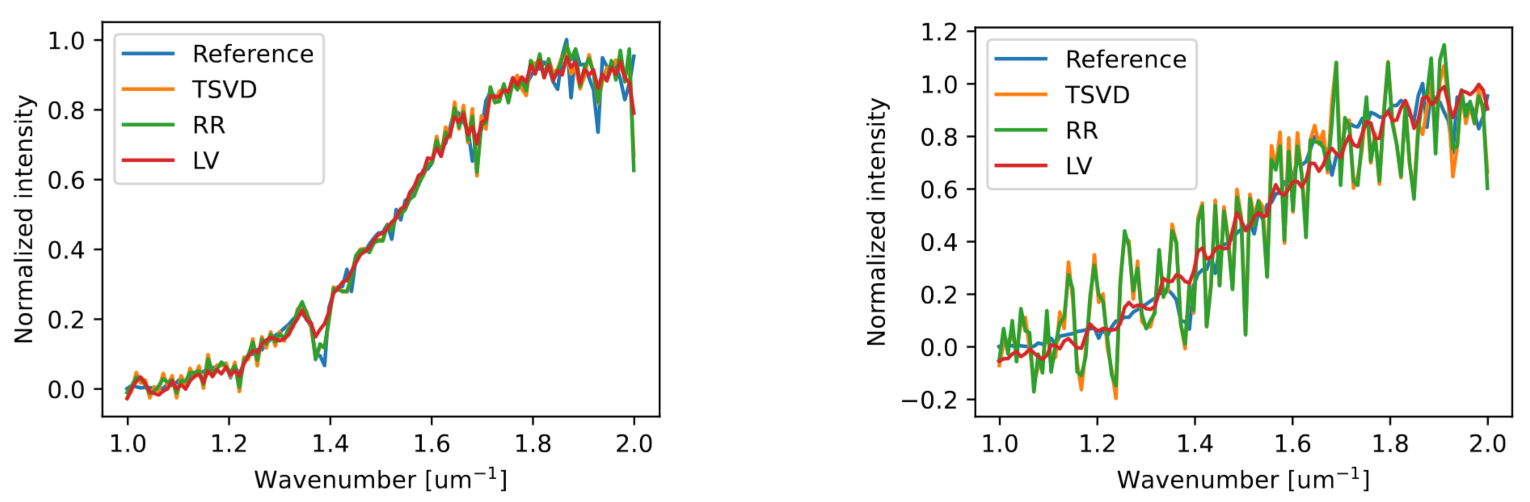
### Conventional methods[3]

- Truncated singular value decomposition (TSVD)
- Ridge regression (RR)

### Iterative methods: Loris-Verhoeven (LV) algorithm[4]

- Solve $\quad \hat{\mathbf{x}} = \operatorname{argmin}_{\mathbf{x}} \frac{1}{2}\|\mathbf{y} - \mathbf{A}\mathbf{x}\|_2^2 + \lambda\, g(\mathbf{W}\mathbf{x}) \quad$ where:
  - $\lambda$ is the regularizing parameter
  - $g(\cdot)$ is the regularization term
  - $\mathbf{W}$ is a linear domain transformation
- Impose sparsity on the Fourier domain of the spectrum: [Our Proposal]
  - Set $\mathbf{W} \in \mathbb{R}^{K \times K}$ as the type-II discrete cosine transform (DCT)
  - Choose $g(\cdot) = \|\cdot\|_1$ as the $\ell_1$-norm (sparsity-inducing regularizer)
  - Solve using *proximal operators* within a primal/dual problem

## Results and Conclusions




SNR = 60 dB

SNR = 40 dB

### Summary

- Iterative methods are efficient as a **base-line** in the presence of noise
- Problem: Induced smoothness with low SNR => **Information loss**
- Problem: The method does not work with real acquisitions => **Model mismatches**
- Technological limitation: The **spectral resolution is limited** by the prototype's design
- **Exploit spatial information** => imaging denoisers and data-based approaches

## Perspectives

- Use better denoisers (test the family of Plug-and-Play denoisers)
- Reduce model mismatches through deep priors that fit with the data
- Challenge: Data is scarce and hard to acquire
- Exploit spatial information: From "one-pixel" to "full-image" inversion

## References


1. Hecht, Eugene. *Optics (5th edition)*. Pearson Education India, 2016.
2. Picone, Daniele, et al. "Interferometer response characterization algorithm for multi-aperture Fabry-Perot imaging spectrometers." arXiv preprint arXiv:2303.14076 (2023).
3. Idier, Jérôme, ed. *Bayesian approach to inverse problems*. John Wiley & Sons, 2013.
4. Ignace Loris and Caroline Verhoeven, "On a generalization of the iterative soft-thresholding algorithm for the case of nonseparable penalty," Inverse Problems, vol. 27, no. 12, pp. 125007, 2011.



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