Compressive Hyperspectral Imaging with Fourier Transform Interferometry

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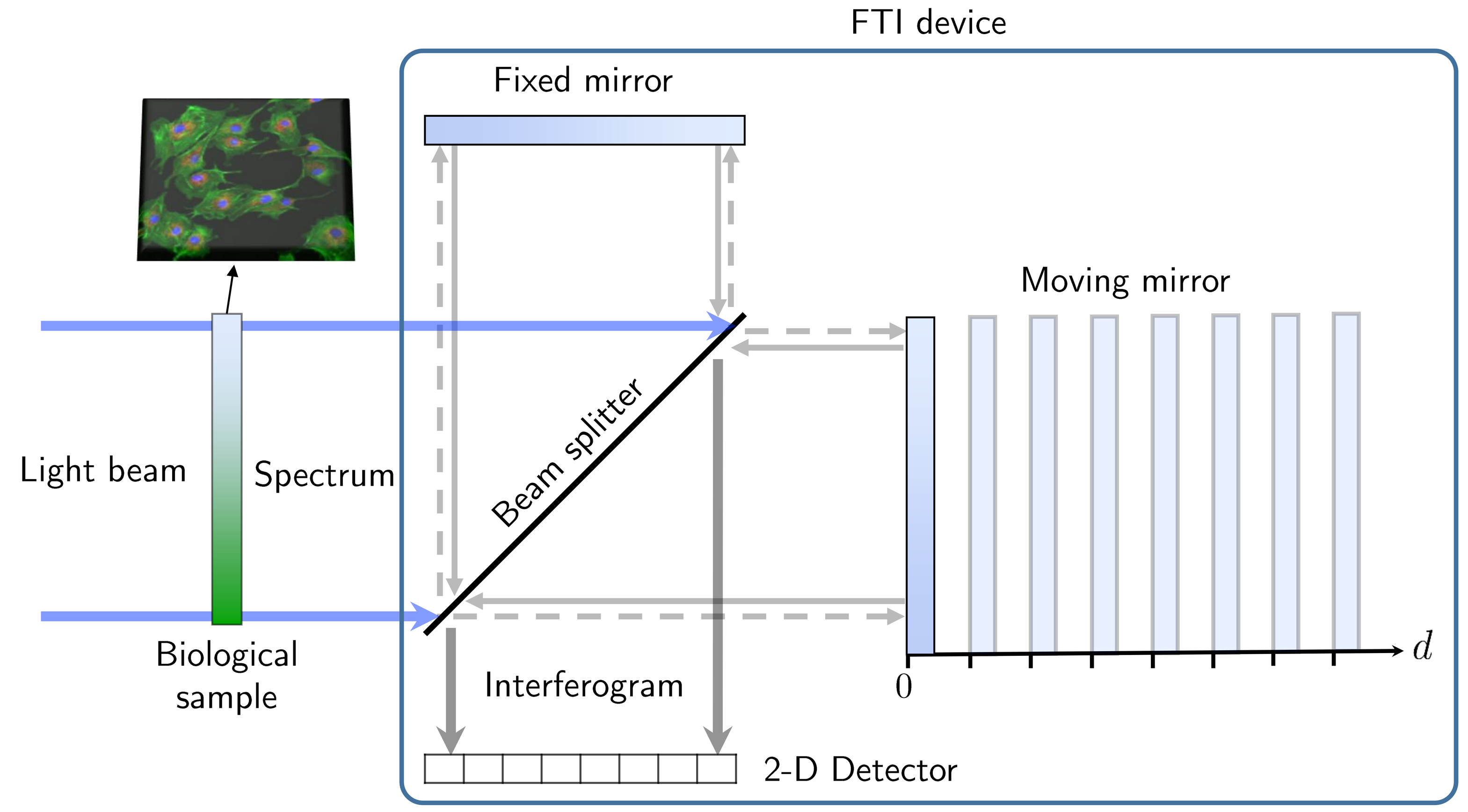
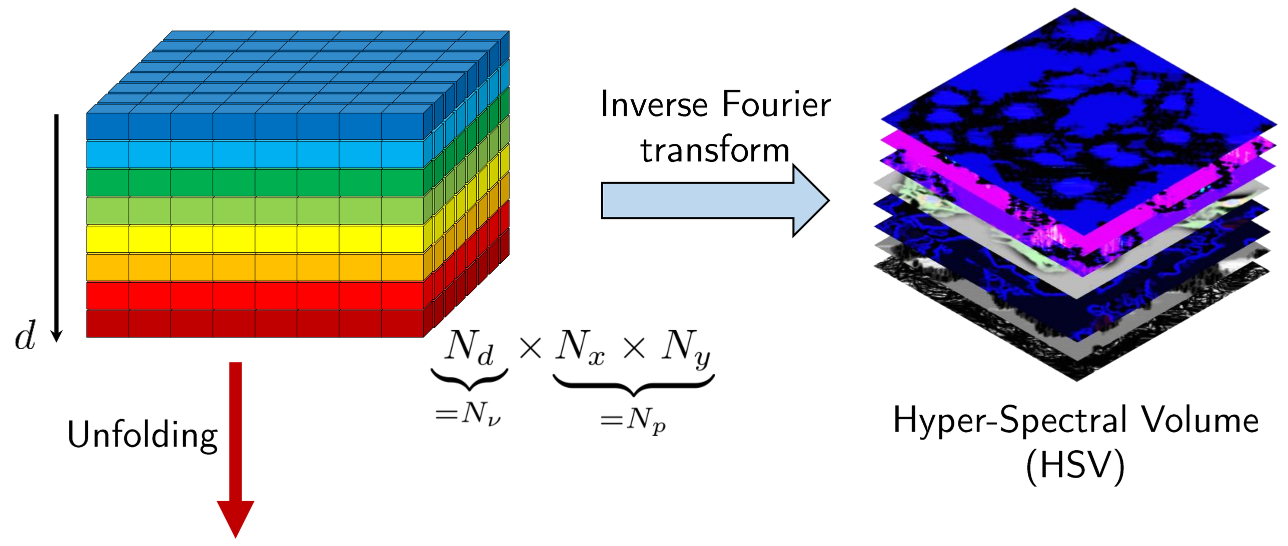
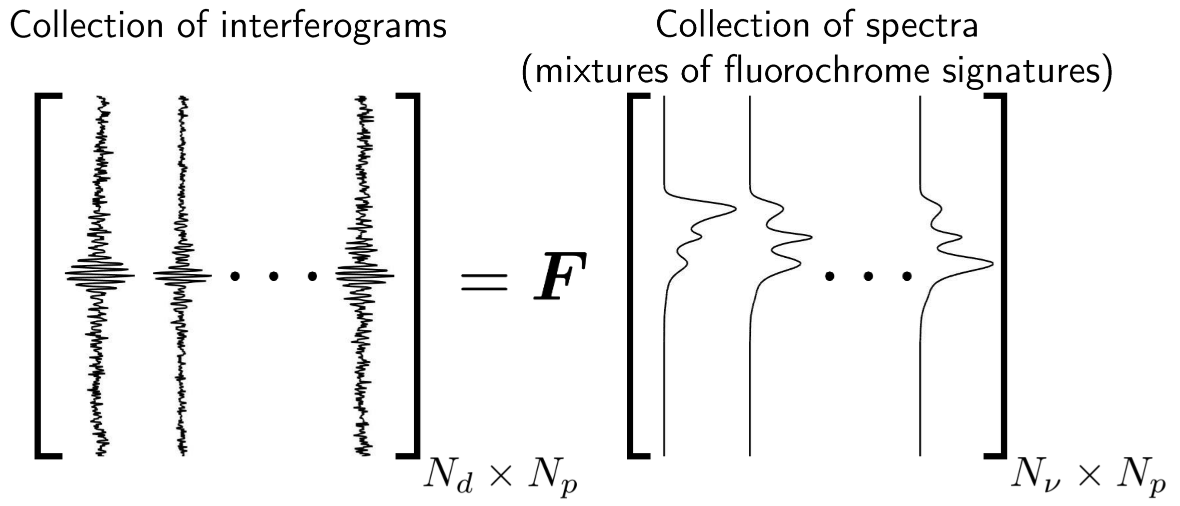
1. Summary

- **Goal:** Fast acquisition of Hyper-spectral (HS) data using Fourier transform interferometry (FTI)
- **Motivations:** Application of FTI in biology, *e.g.*, fluorescence spectroscopy
  - ✔ FTI can reach high resolution without reducing SNR
  - ✗ Higher resolution ⇒ longer acquisition time ⇒ more photo-bleaching (photochemical alteration of the dyes)
- **Contribution:** Resorting the theory of compressed sensing (CS) to reduce the number of FTI measurements ⇒ shorter acquisition time/less light exposure
- **Challenges:** Low-complexity model, sub-sampling technique

2. Conventional (Nyquist) FTI



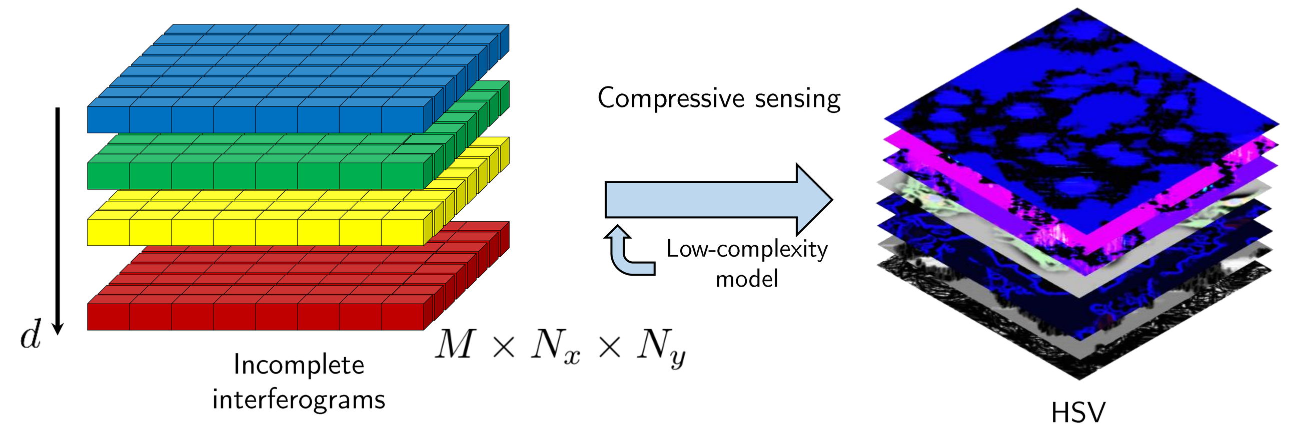




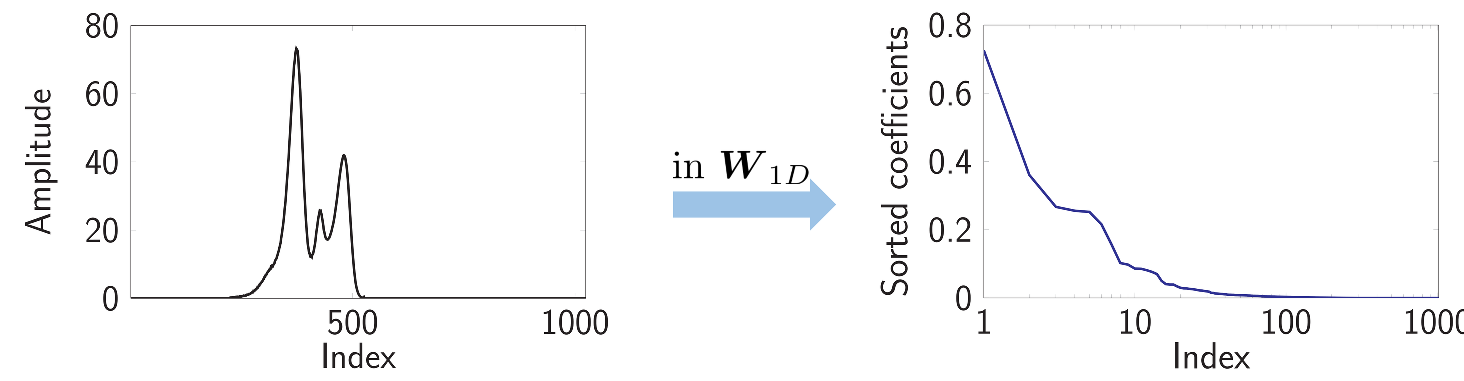
Acquisition model: $Y^{\mathrm{Nyq}} = FX$ (Fourier matrix: F)

3. Compressive Sensing-FTI (CS-FTI)

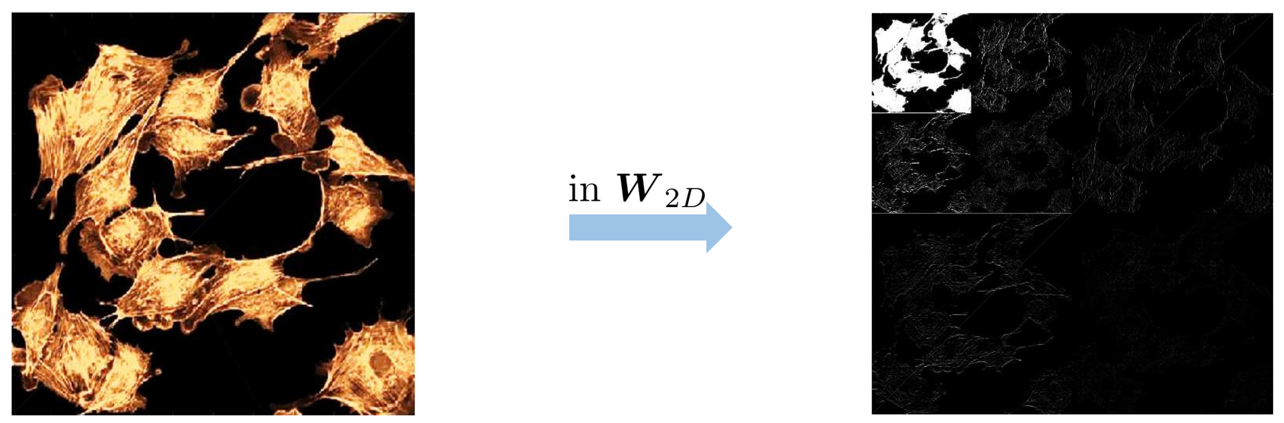
- Interferogram signals are acquired at M mirror positions ($M \ll N_\nu$).



- Low-complexity model
  - ▷ Spectral domain ≡ columns of X: compressible in 1D wavelet bases, *i.e.*, $W_{1D} \in \mathbb{R}^{N_\nu \times N_\nu}$.



  - ▷ Spatial domain ≡ rows of X: compressible in 2D wavelet bases, *i.e.*, $W_{2D} \in \mathbb{R}^{N_p \times N_p}$.



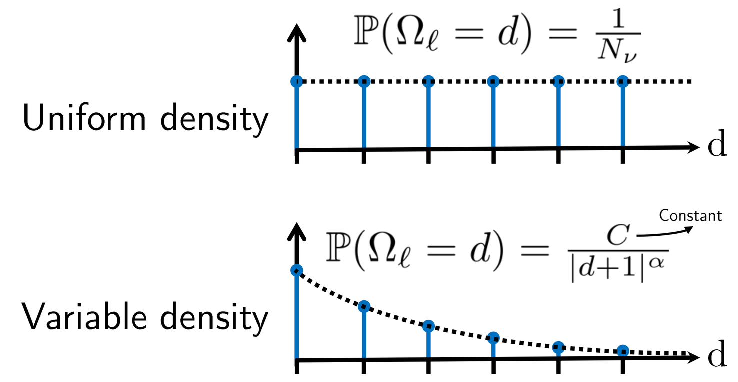
  - ▷ **Joint spectral-spatial sparsity**

$$X = W_{1D} S W_{2D}^T$$
$$|\mathrm{supp}(s)| \le K < M,\ s = \mathrm{vec}(S)$$

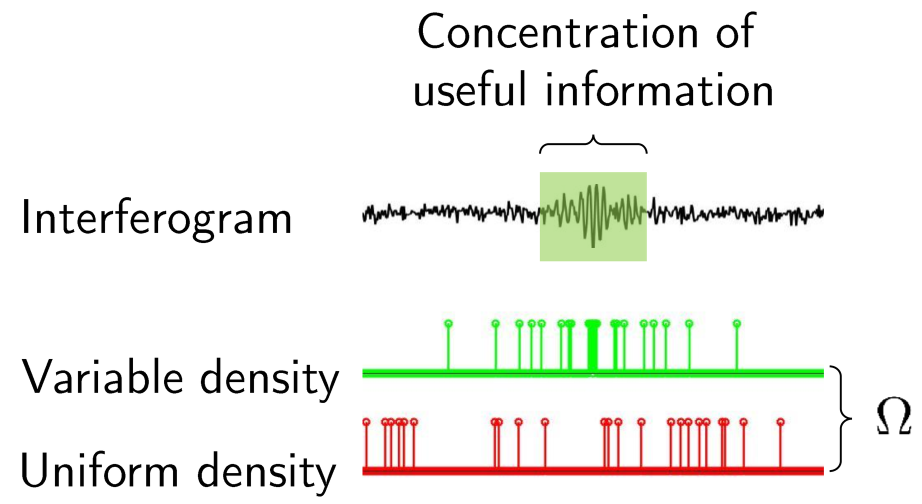
- Sampling model

Acquisition model:
$$Y = I_\Omega^T F X$$

Recorded mirror positions:
$$\Omega \subset \{1, \cdots, N_\nu\},\ |\Omega| = M$$



A variable density sampling with power-law decay distribution [1] is a superior candidate



- Reconstruction

$$\hat{S} = \operatorname*{argmin}_{U \in \mathbb{R}^{N_\nu \times N_p}} \|\mathrm{vec}(U)\|_1 \quad \text{s.t} \quad Y = I_\Omega^T F W_{1D} U W_{2D}^T$$
$$\hat{X} = W_{1D} \hat{S} W_{2D}^T \qquad (1)$$

4. Numerical Results

- Synthetic ground-truth HSV of size $64 \times 128 \times 128$.
- Solving Problem. 1 using Douglas-Rachford algorithm [2].

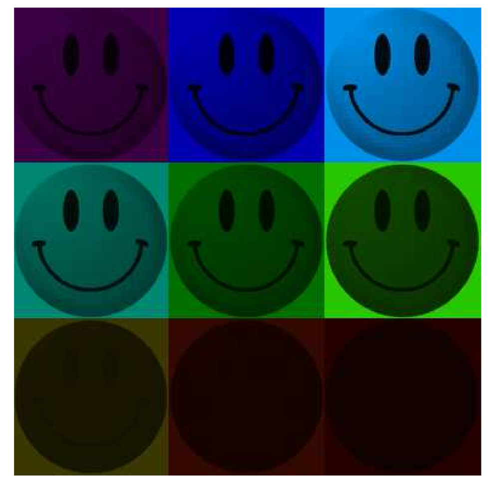


Figure 1: Illustration of nine spectral bands of the ground-truth HSV.

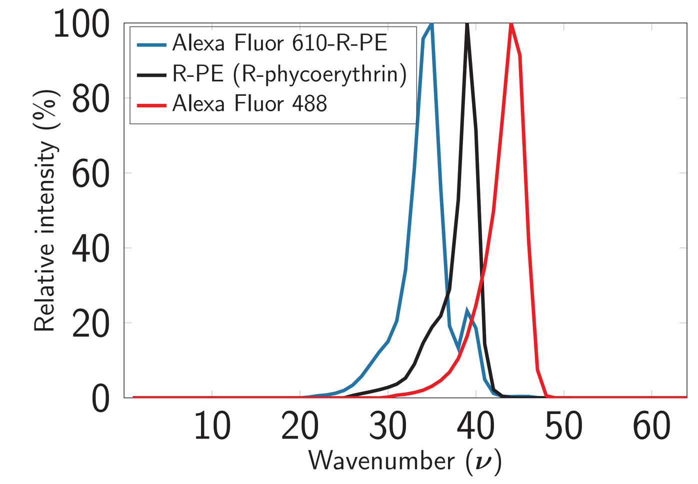


Figure 2: Fluorochrome signatures used for generation of the ground-truth HSV.

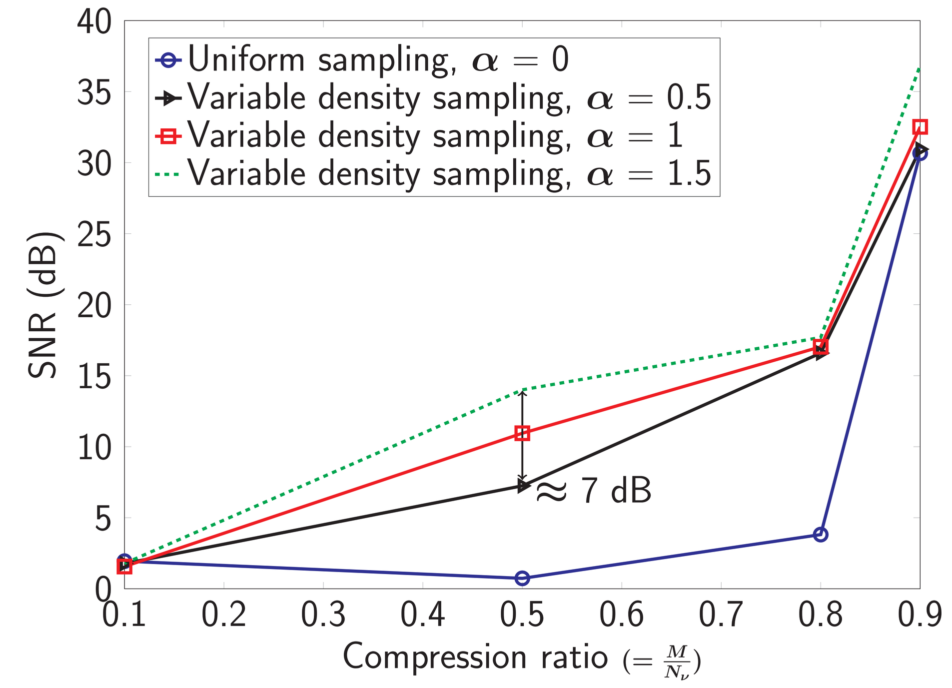


Figure 3: Reconstruction performance of uniform ($\alpha = 0$) and variable density sampling ($\alpha \in \{0.5, 1, 1.5\}$).

5. Take Home Message

- We presented a proof of concept for turning a conventional FTI into a fast CS-FTI.
- The HSV is sparse (or compressible) in the Kronecker product of 1D and 2D wavelet bases.
- Uniform density sampling should be modified to a variable density scheme by exploiting the coherency between sparsity and sampling bases.

6. References

[1] F. Kramher and R. Ward, "Stable and robust sampling strategies for compressive imaging," *IEEE Transactions on Imaging Processing*, vol. 23, no. 2, pp. 612–622, 2013.

[2] P. L. Combettes and J-C. Pesquet, "Proximal splitting methods in signal processing," *arXiv prepint arXiv:0912.3522*, 2009.

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