Compressive Spectral Imaging in View of Earth Observation Applications

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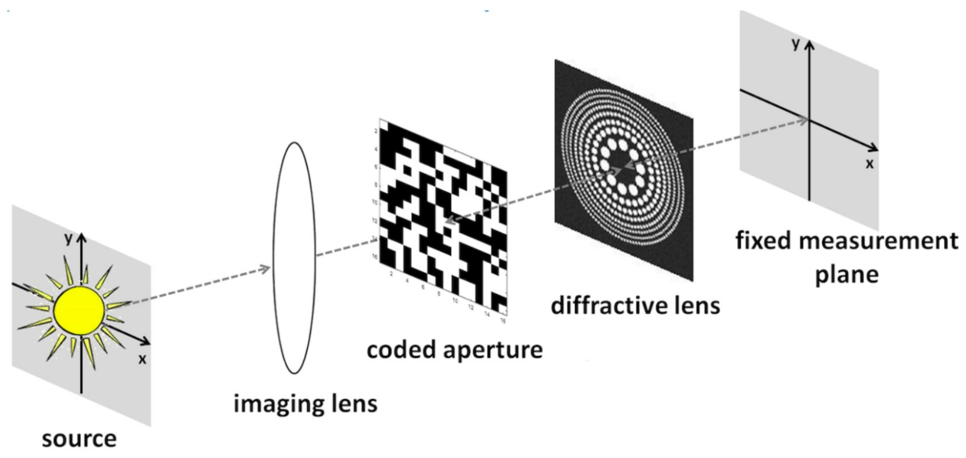
ABSTRACT

Earth observation from space is an important scientific and industrial activity, having applications in many sectors. The instruments employed are often large, complex, and expensive. In addition, they generate large amounts of data which is challenging for storage and transfer purposes. Compressive spectral imaging would be a cheaper, more efficient, and well-adapted technique to perform Earth observation. An interesting architecture is compressive spectral imaging with diffractive lenses which is extremely compact. This work investigates the possibility of replacing the diffractive lens in this system with a classical refractive lens. Indeed, taking advantage of the chromatic aberration of a lens makes the use of expensive diffractive lenses unnecessary. Simulations are performed to test the feasibility of the method. The signal recovery is performed by the resolution of an inverse problem, in particular, a basis pursuit solved using the Douglas-Rashford algorithm.

INTRODUCTION

Compressive Spectral Imaging with Diffractive lenses (CSID) [1] is a technique allowing the acquisition of hyperspectral data with ultra-compact designs by taking advantage of the simultaneous dispersive and focusing behavior of a diffractive lens.



CSID architecture. Adapted from [1].

The proposed method uses the dispersive properties of simple refractive lenses to eliminate the complexity and cost of designing a diffractive lens.

Advantages compared to classical spectral imagers:

- Quasi-instantaneous 3D scene acquisition.
- No scanning system.
- Reduction of data quantities.

METHODS

Measurement model:

$$\underset{(M)}{y} = \underset{(M \times N)}{H}\ \underset{(N \times N)}{C}\ \underset{(N)}{\Psi}\ \underset{(N)}{s}$$

Measurement vector (y); Convolution with the PSFs (H); Coding matrix (C); Sparsifying basis (Ψ); Sparse coefficients (s).

The original spectral volume is $x = \Psi s$. The objective is to retrieve **s**, all other parameters being chosen or measured. Since the system is compressive then M << N, yielding an ill-posed inverse problem. The key is the knowledge of the mask applied to the image and the PSF of each spectral band, along with choosing an appropriate sparsifying basis. In this case, we choose the basis as the Kronecker product of a 2D wavelet transform in the spatial domain and a 1D cosine transform in the spectral domain.

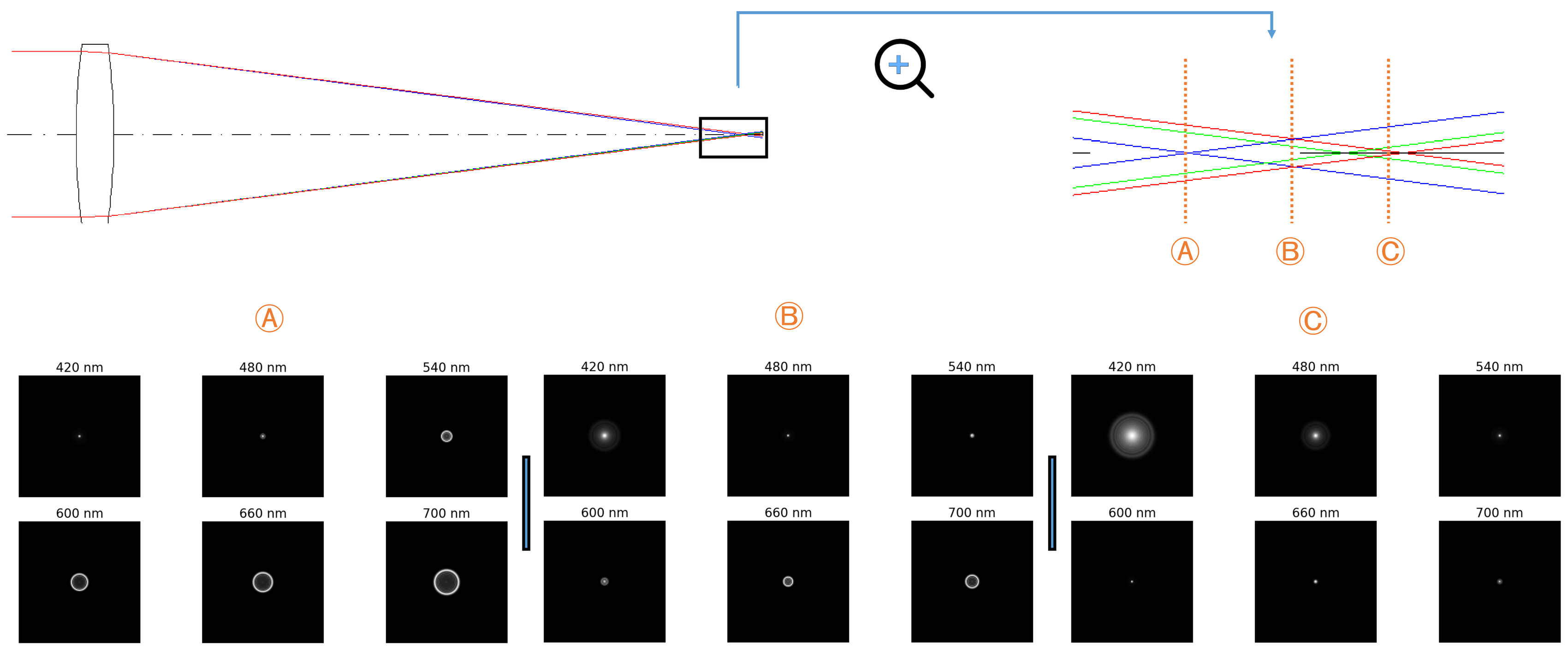
Reconstruction method:

$$s^* = \arg\min_s ||s||_1 s.t. ||y - HC\Psi||_2 \leq \epsilon$$

Where ϵ is the noise tolerance, and the reconstructed volume is $x^* = \Psi s^*$. Minimizing the l_1 norm enforces the sparsity while the second term ensures the fidelity to the data. This basis pursuit [2] problem is solved using the Douglas-Rashford algorithm which is an iterative scheme to minimize the sum of closed proper convex functions that are not necessarily smooth [3].

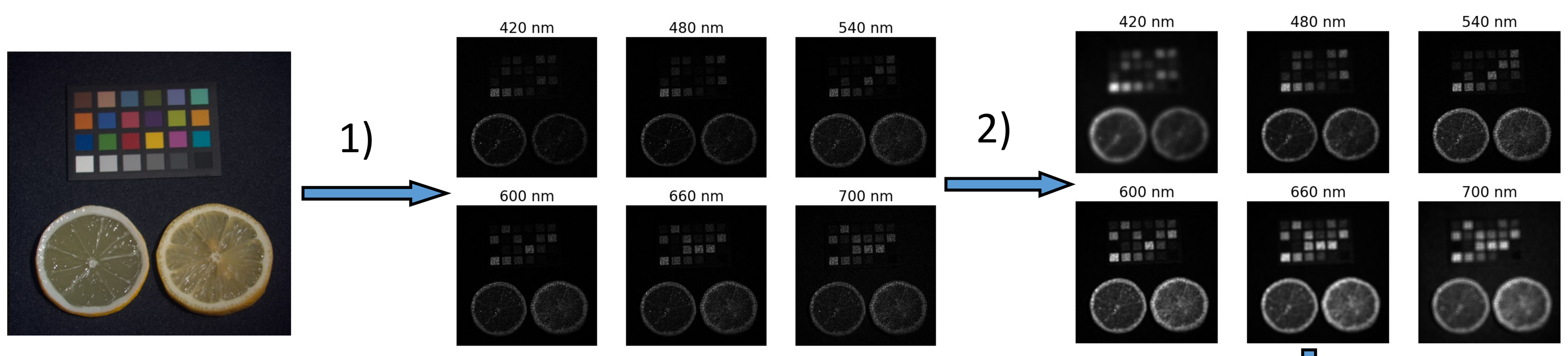
SIMULATION

***Code V* PSF simulation**



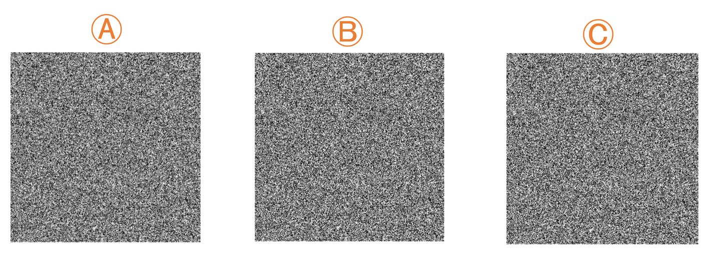
Measurement process

Example Ⓑ



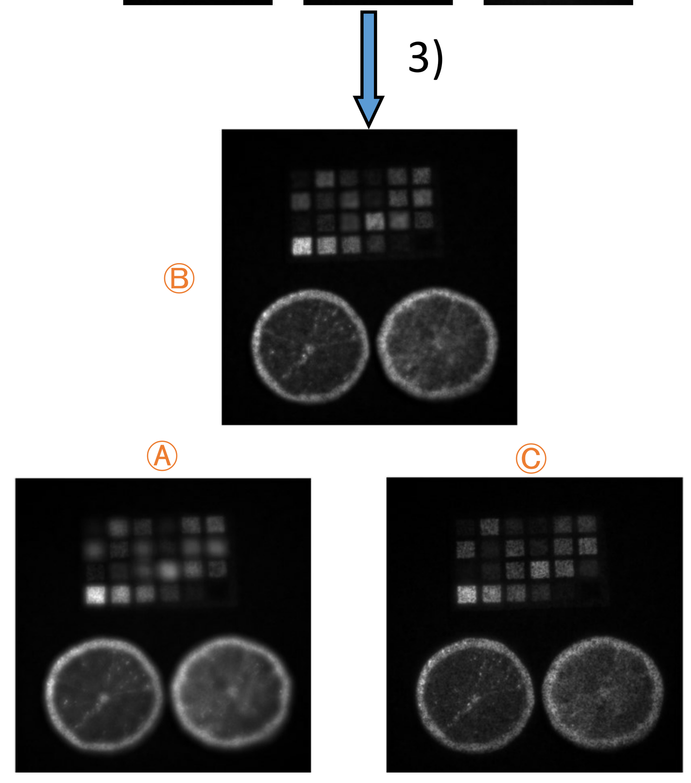
For one measurement:

1) All bands are coded with the same mask.

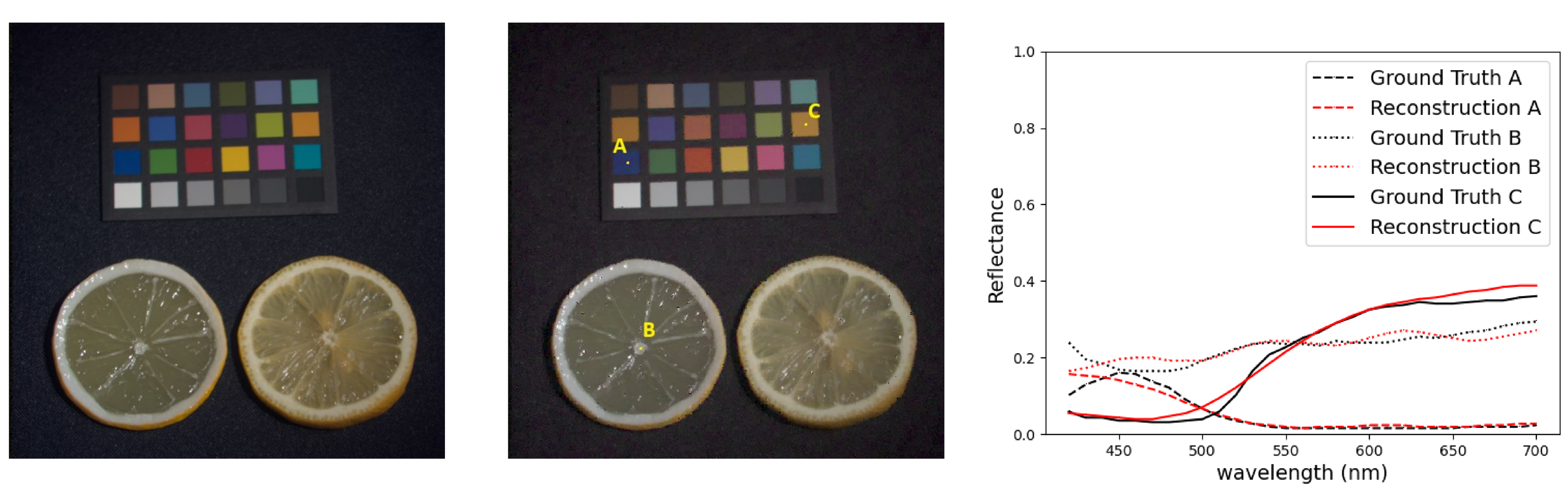


2) Convolution of each band with its corresponding PSF.

3) Superposition of all coded and blurred spectral bands.



3 measurements are taken in total



Conclusion

Simulations show promising results for the design of a compressive spectral imager using only two refractive lenses, a spatial light modulator, and a monochrome detector. Future work will be the implementation in the laboratory.

References

[1] O.F. Kar and F.S. Oktem, "Compressive spectral imaging with diffractive lenses," *Optics letters*, vol. 44, no. 18, pp. 4582-4585, 2019.

[2] S.S. Chen, D.L. Donoho, and M.A. Saunders, "Atomic decomposition by basis pursuit," *SIAM review*, vol. 43, no. 1, pp. 129-159, 2001.

[3] P.L. Combettes and J.-C. Pesquet, "Proximal splitting methods in signal processing," *Fixed-point algorithms for inverse problems in science and engineering*, pp. 185-212, 2011.

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