Hierarchical Compressed Subspace Clustering of Infrared Single-pixel Measurements


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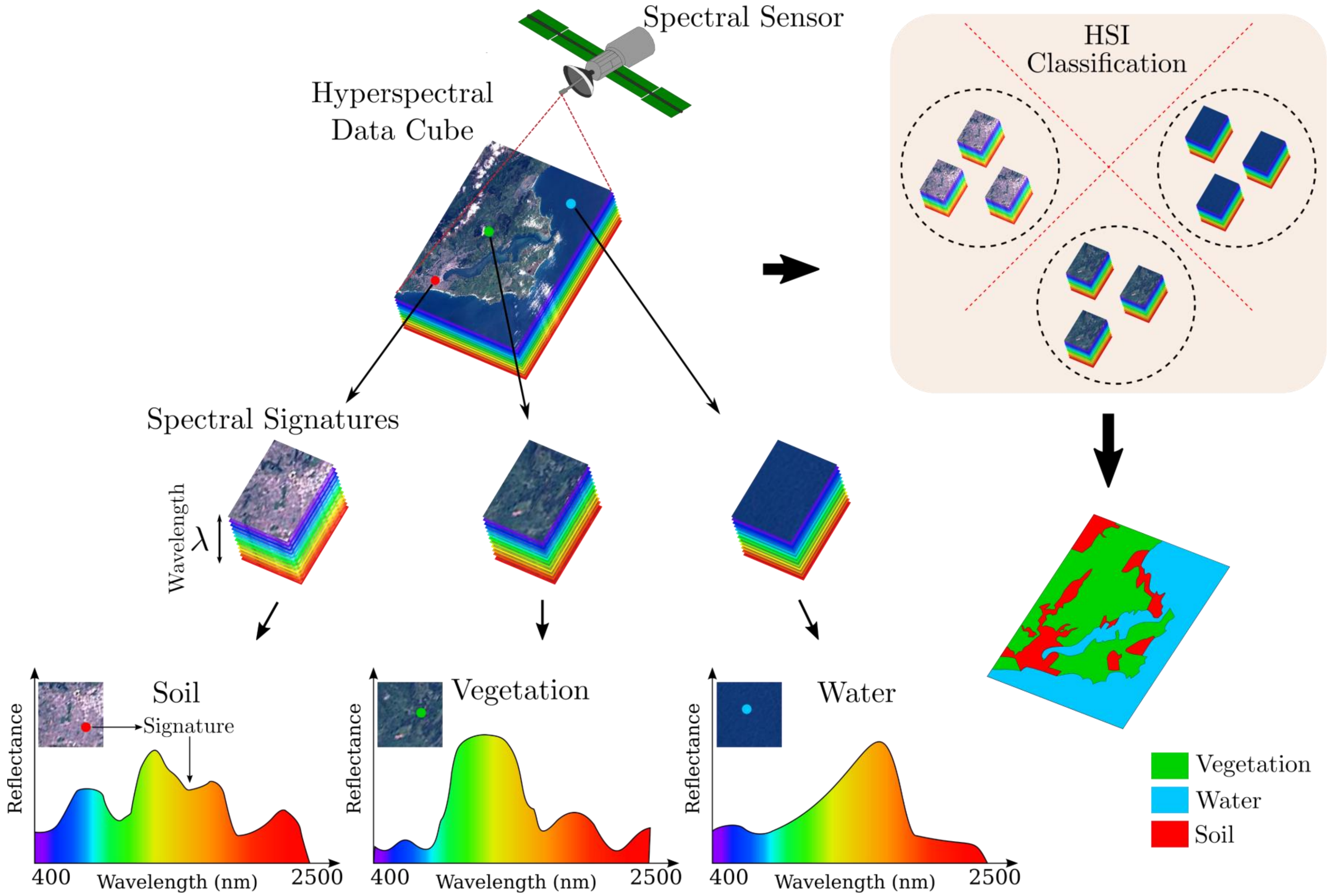
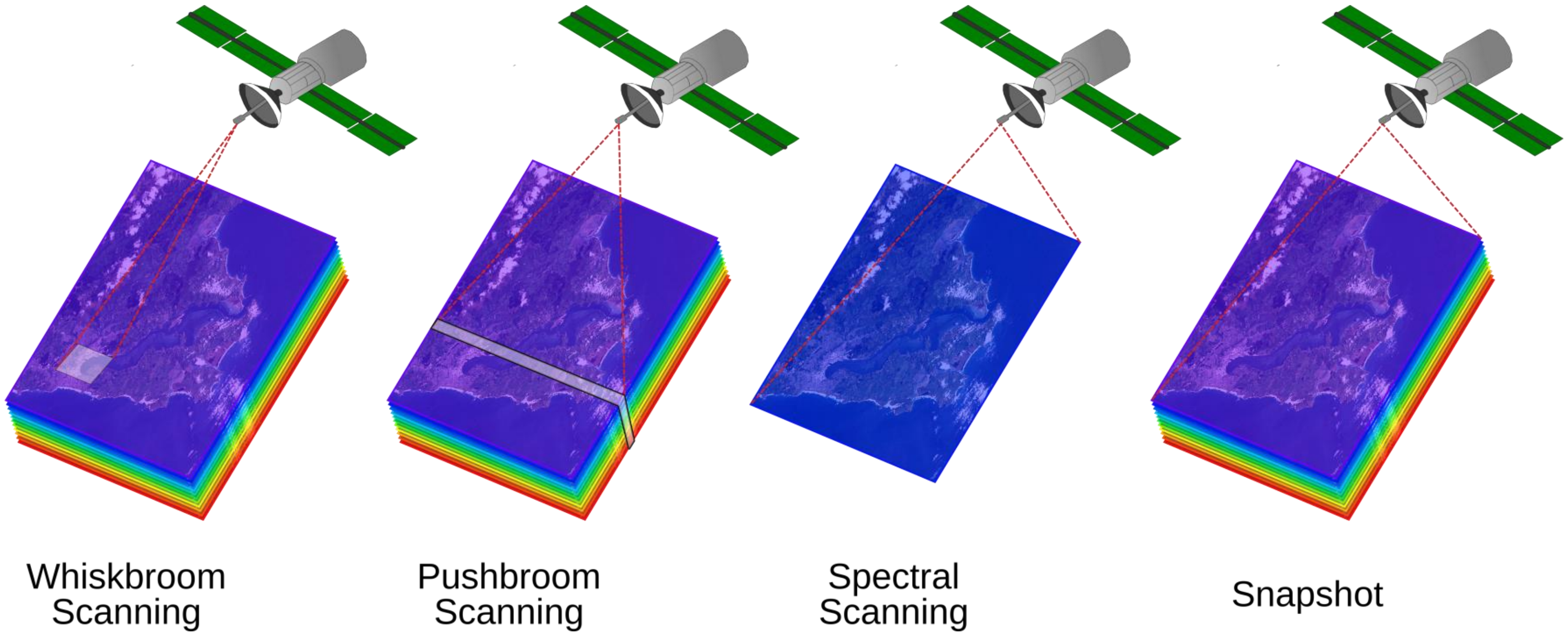
HSI Clustering

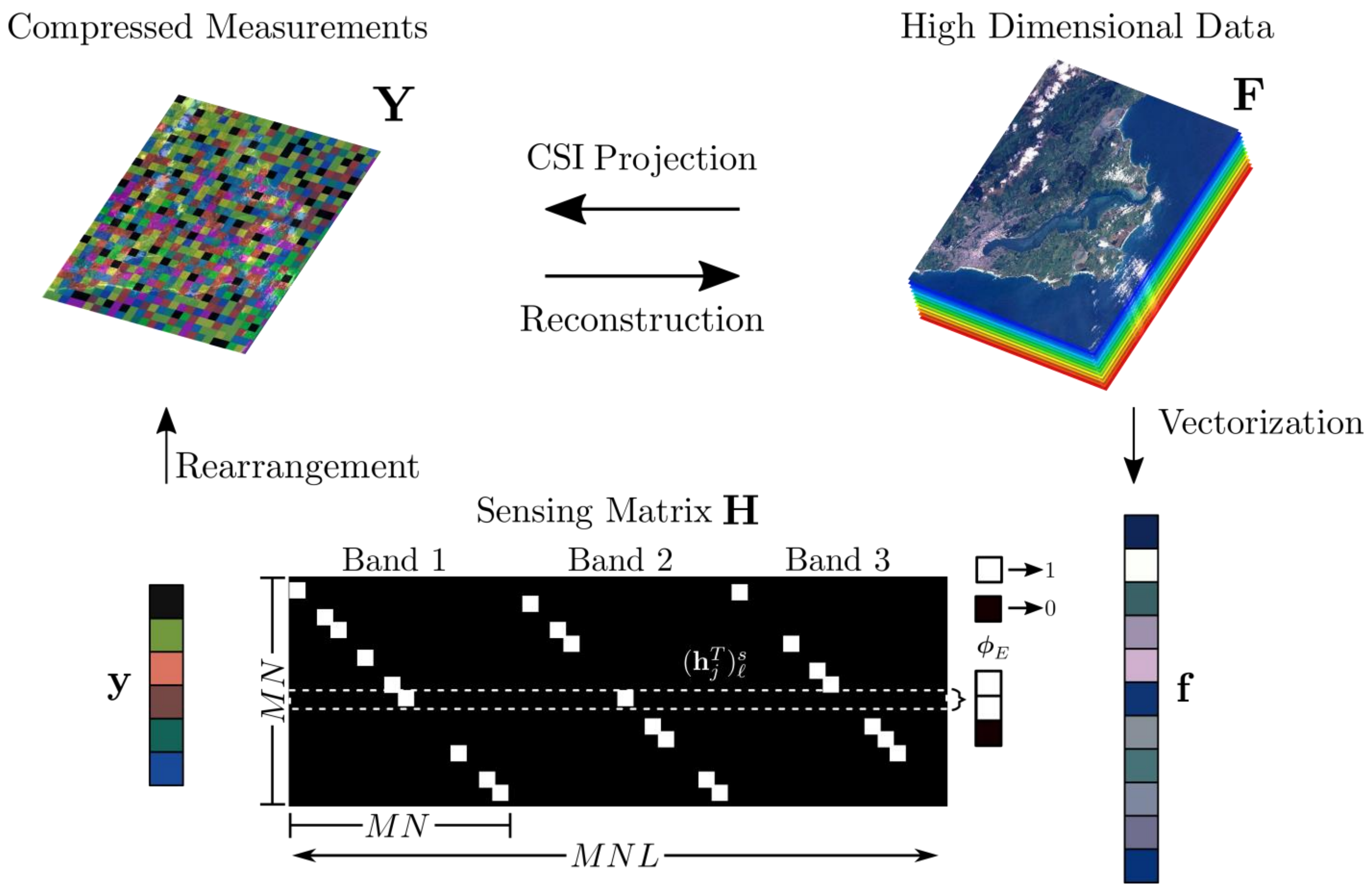


Hyperspectral imaging



- Traditional hyperspectral imaging techniques relies on Nyquist-Shannon sampling theorem.
- Require a fixed sampling rate along the three dimensions, leading to a **large amount of captured data** and **large acquisition times.**

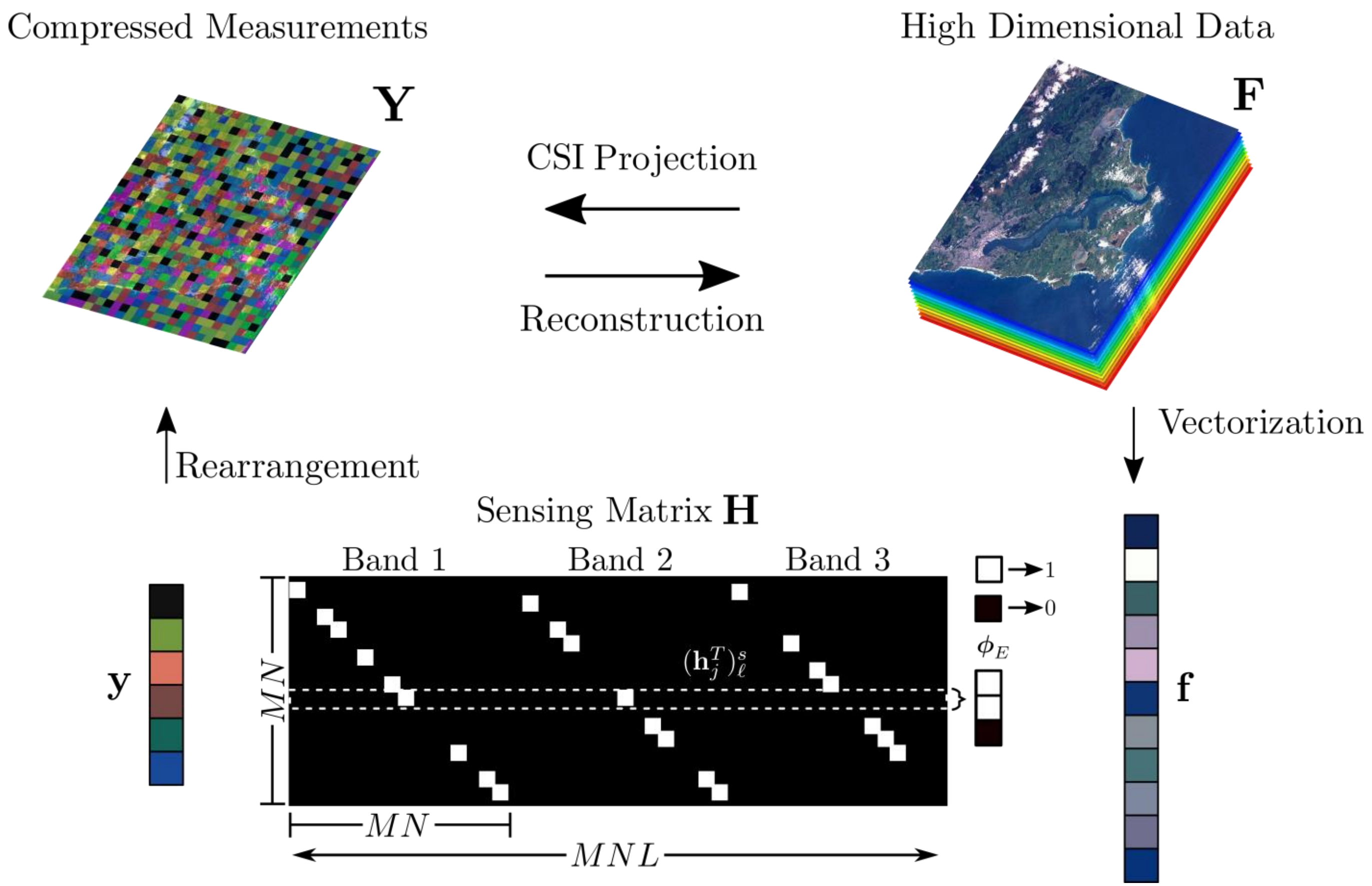
Compressive Spectral Imaging (CSI)



- Senses and simultaneously reduces the data dimension without any further processing step.
- Captures less samples than traditional methods.
- Assumes that $\mathbf{f}$ can be represented as a sparse vector $\boldsymbol{\theta}$ in some basis

$$\boldsymbol{\Psi}, \text{ i.e, } \mathbf{f} = \boldsymbol{\Psi}\boldsymbol{\theta}.$$

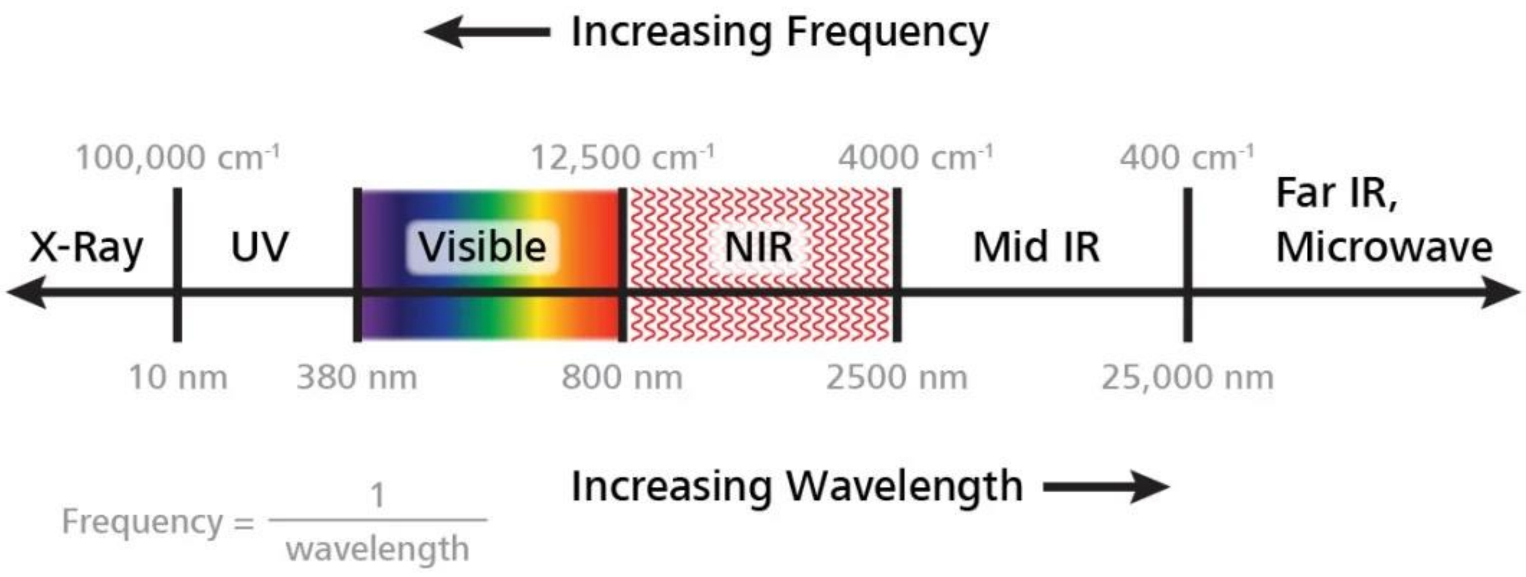
Compressive Spectral Imaging



- Then, the acquisition process can be modeled as $\mathbf{y} = \mathbf{H}\mathbf{f}$, where $\mathbf{H}$ is the sensing matrix of the system.
- Using $\mathbf{g}$ and taking advantage of sparsity of $\mathbf{f}$, the original full HSI can be recovered as

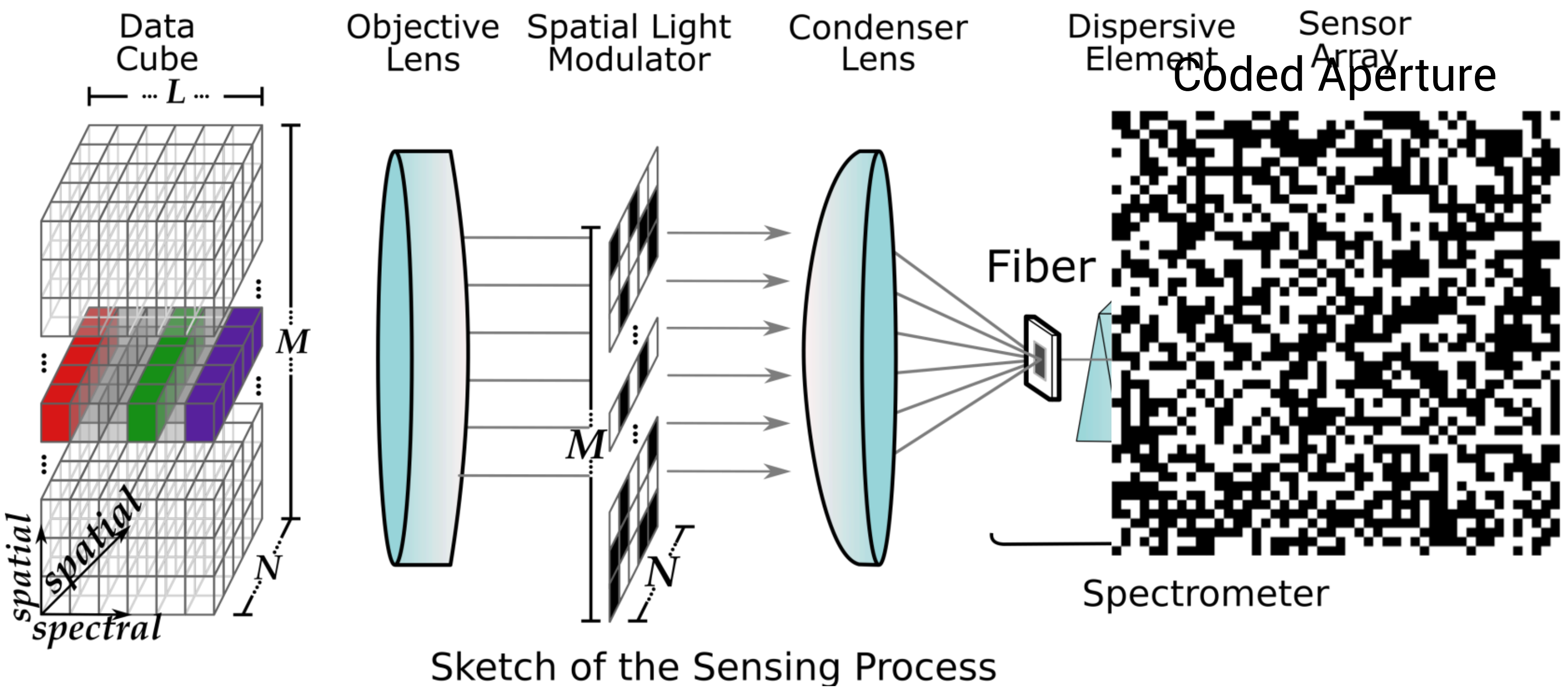
$$\hat{\mathbf{f}} = \mathbf{\Psi}\left\{\underset{\boldsymbol{\theta}}{\arg\min}\, \|\mathbf{H}\mathbf{\Psi}\boldsymbol{\theta} - \mathbf{g}\|_2^2 + \lambda\|\boldsymbol{\theta}\|_1\right\}$$

From visible spectrum to NIR



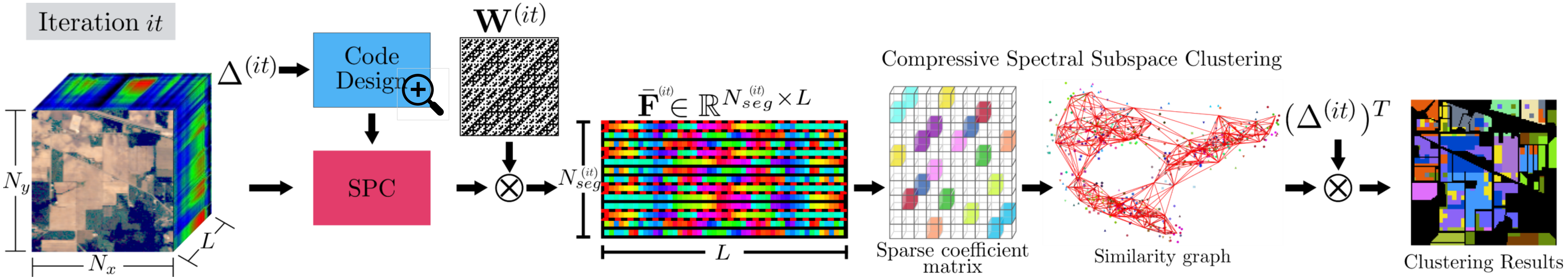
- Traditionally the scenes are acquired inside the visible spectrum range, i.e., beginning at 400 nm.
- This paper develops a clustering approach to obtain unsupervised pixel classification directly from the compressive infrared single-pixel camera (SPC) domain **(900 - 2500 nm).**

Single pixel camera



- **SPC architecture excels due to its low implementation cost** when acquiring a large number of spectral band.

Proposed Method



Downsampling Matrix Design

Algorithm 1 Downsampling Matrix Design

Require: $N_{seg}, \bar{\mathbf{F}}$
Ensure: $\boldsymbol{\Delta}$

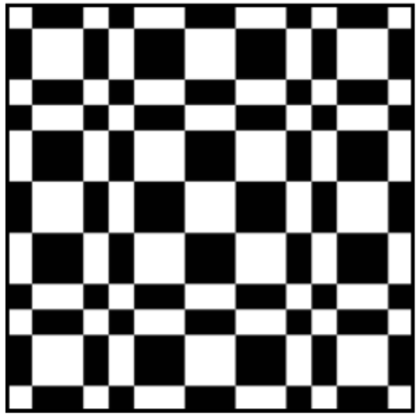
```
procedure DSAMPLING_DESIGN(F̄, N_seg)
    k_idx ← RegularSegms(F̄, N_seg)        ▷ k_idx contains the segment labels
    Δ ← zeros(N_seg, length(k_idx))
    for e ← 1 to N_seg do
        p^e ← find(k_idx = e)
        n_e ← length(p^e)
        for j ← 1 to n_e do
            (δ_e)^T_{(p^e)_j} = 1/n_e      ▷ Update each row of Δ
        end for
    end for
    return Δ
end procedure
```

$$\mathbf{H} = \mathbf{W}\boldsymbol{\Delta}$$

$\mathbf{W} \in \{-1, 1\}^{K \times K} \longrightarrow$ Hadamard Matrix

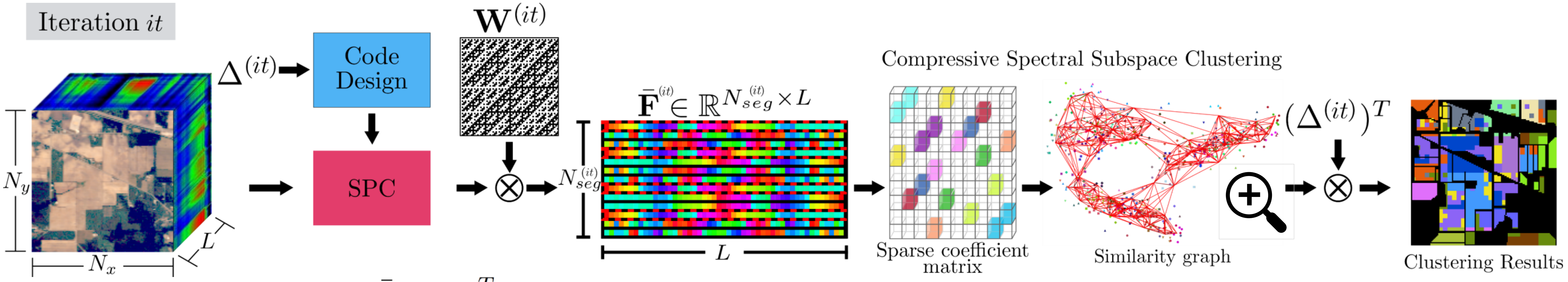
$\boldsymbol{\Delta} \in \mathbb{R}^{N_{seg} \times MN} \longrightarrow$ Decimation matrix

$$\tilde{\mathbf{f}}_l = (1/K)\boldsymbol{\Delta}^T\mathbf{W}^T\mathbf{y}_l = (1/K)\boldsymbol{\Delta}^T\mathbf{W}^T\mathbf{W}\boldsymbol{\Delta}\mathbf{f}_l \approx \mathbf{f}_l$$



Designed coded aperture example

Proposed Method



$$\bar{\mathbf{f}}_l = \mathbf{W}^T \mathbf{y}_l = \boldsymbol{\Delta} \mathbf{f}_l$$

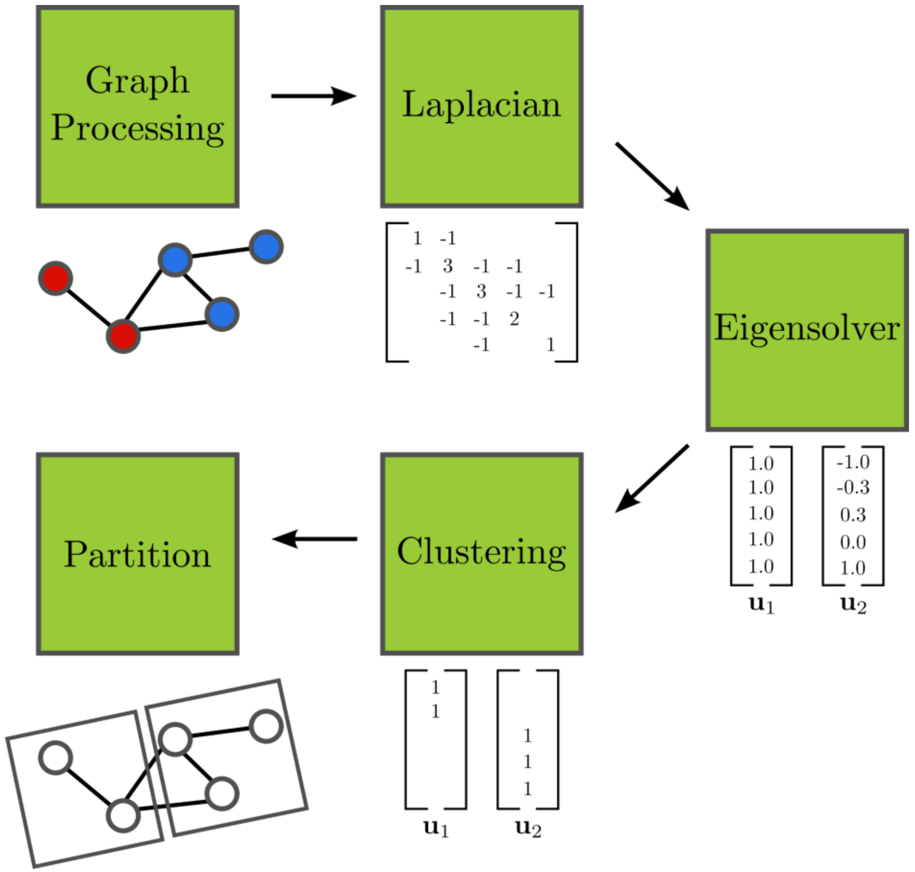
- Instead of performing the complete reconstructions, it is possible to directly extract features from the compressed measurements.

Compressive spectral subspace clustering

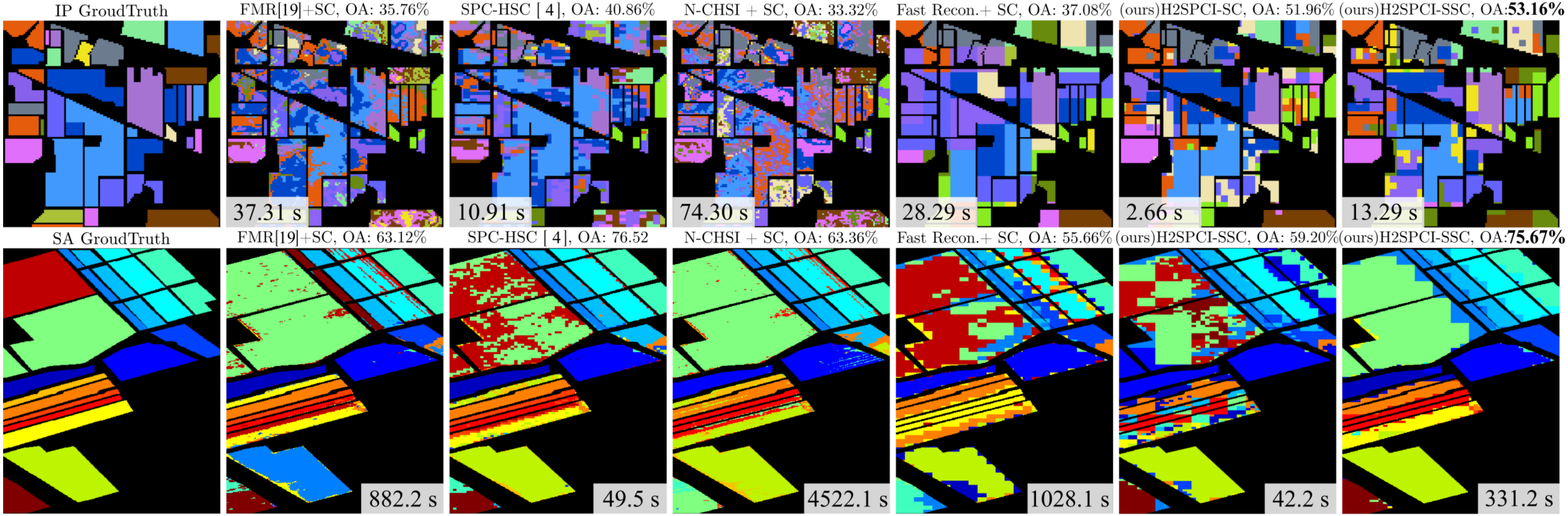
Algorithm 2 Data Clustering

Require: $\bar{\mathbf{F}} \in \mathbb{R}^{N_{seg} \times L}$, $\boldsymbol{\Delta}$ downsampling matrix, κ clusters
Ensure: Segmentation of the spectral pixels: $\mathbf{F}_1, \cdots, \mathbf{F}_k$

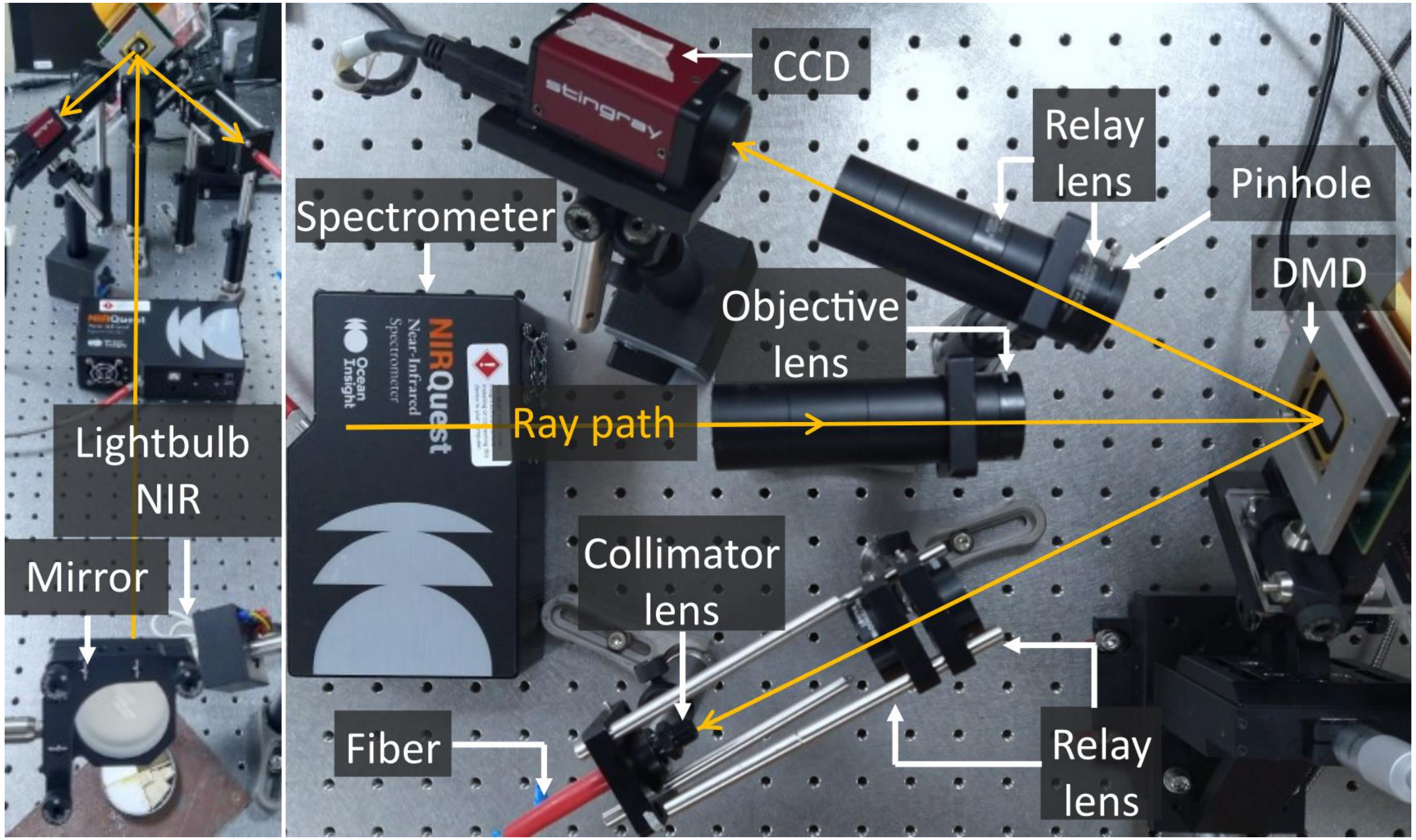
procedure DATA_CLUSTERING($\bar{\mathbf{F}}, \boldsymbol{\Delta}, \kappa$)
  $\mathbf{G} \leftarrow$ Build_Sim_Graph($\bar{\mathbf{F}}$) ▷ κ-nearest neighbor graph ▷ Obtain Cluster indices
  $\bar{\mathbf{C}}_{idx} \leftarrow$ Spectral_Clustering($\mathbf{G}, \kappa$) ▷ Spectral Clustering [19]
  $\mathbf{C}_{idx} \leftarrow \boldsymbol{\Delta}^T \bar{\mathbf{C}}_{idx}$ ▷ Upsampling
end procedure



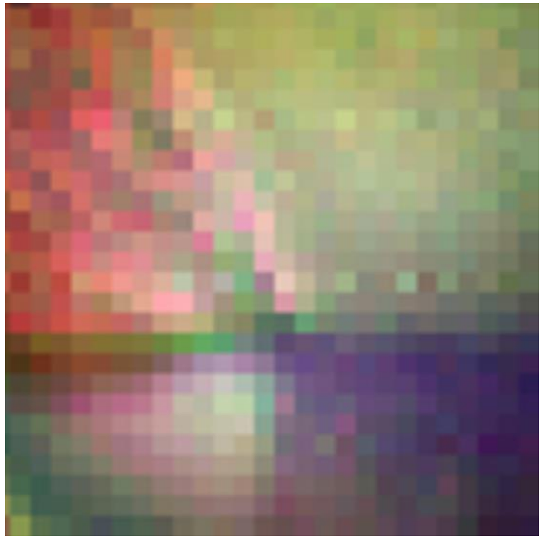
Simulations



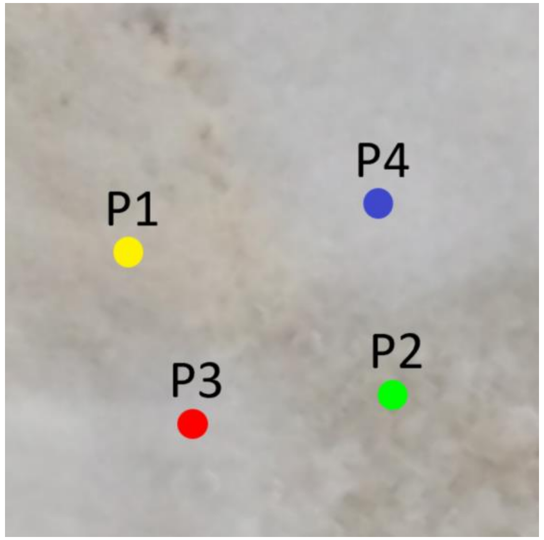
Experimentation



Experimental Setup

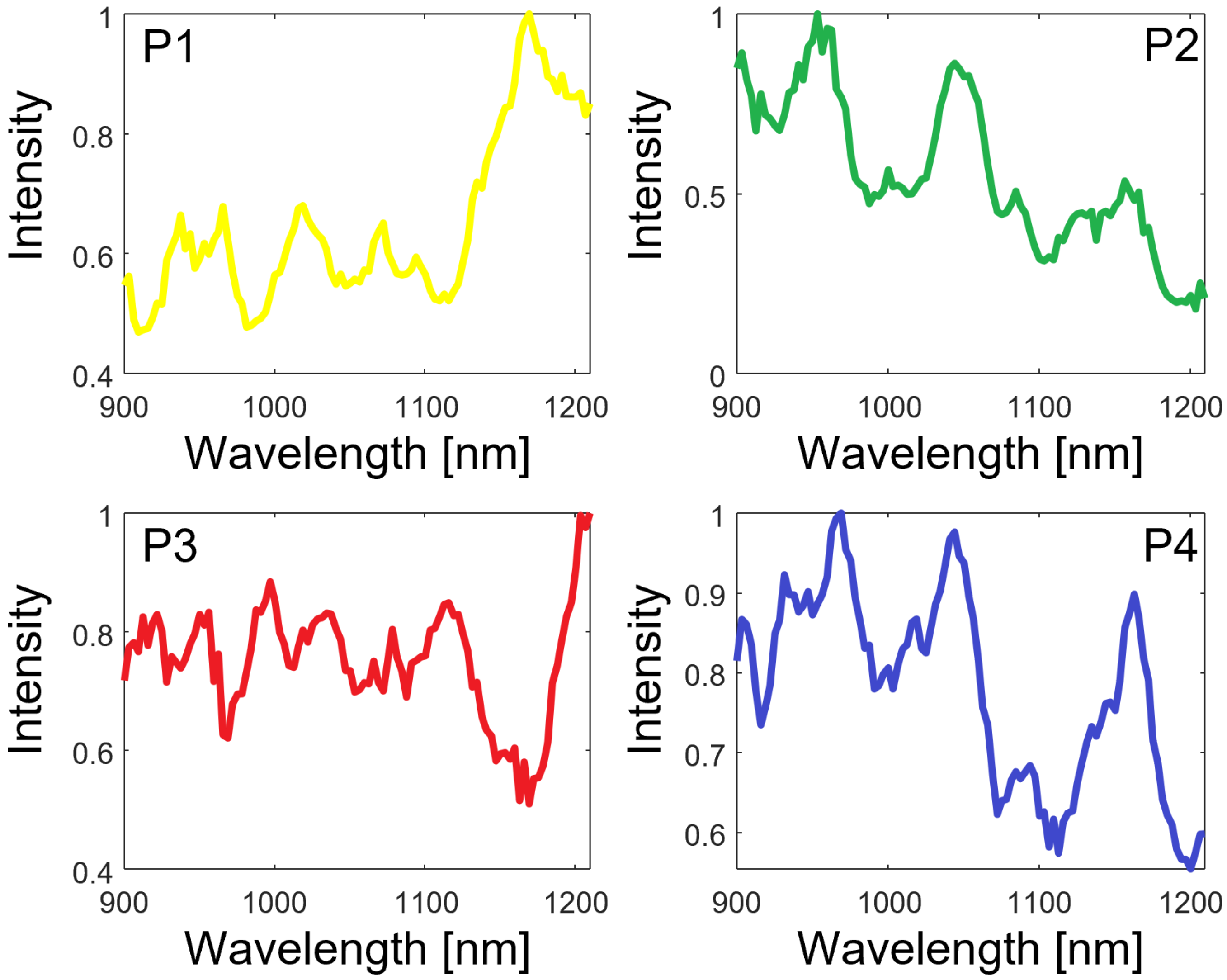


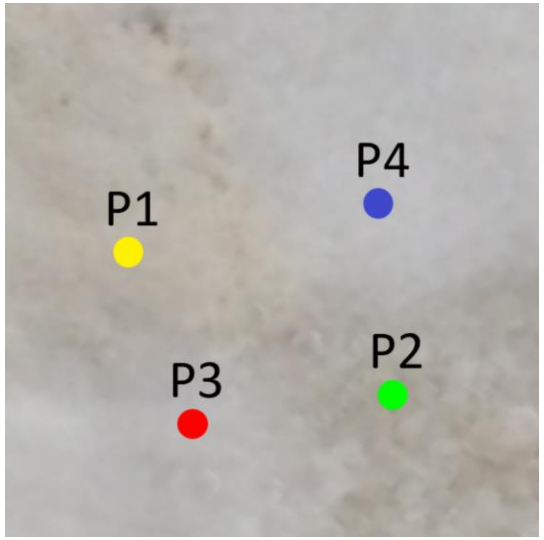
False RGB composite



RGB composite acquired with a traditional camera

Experimentation

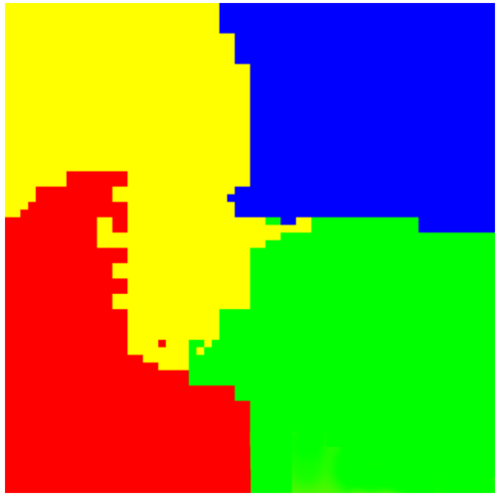




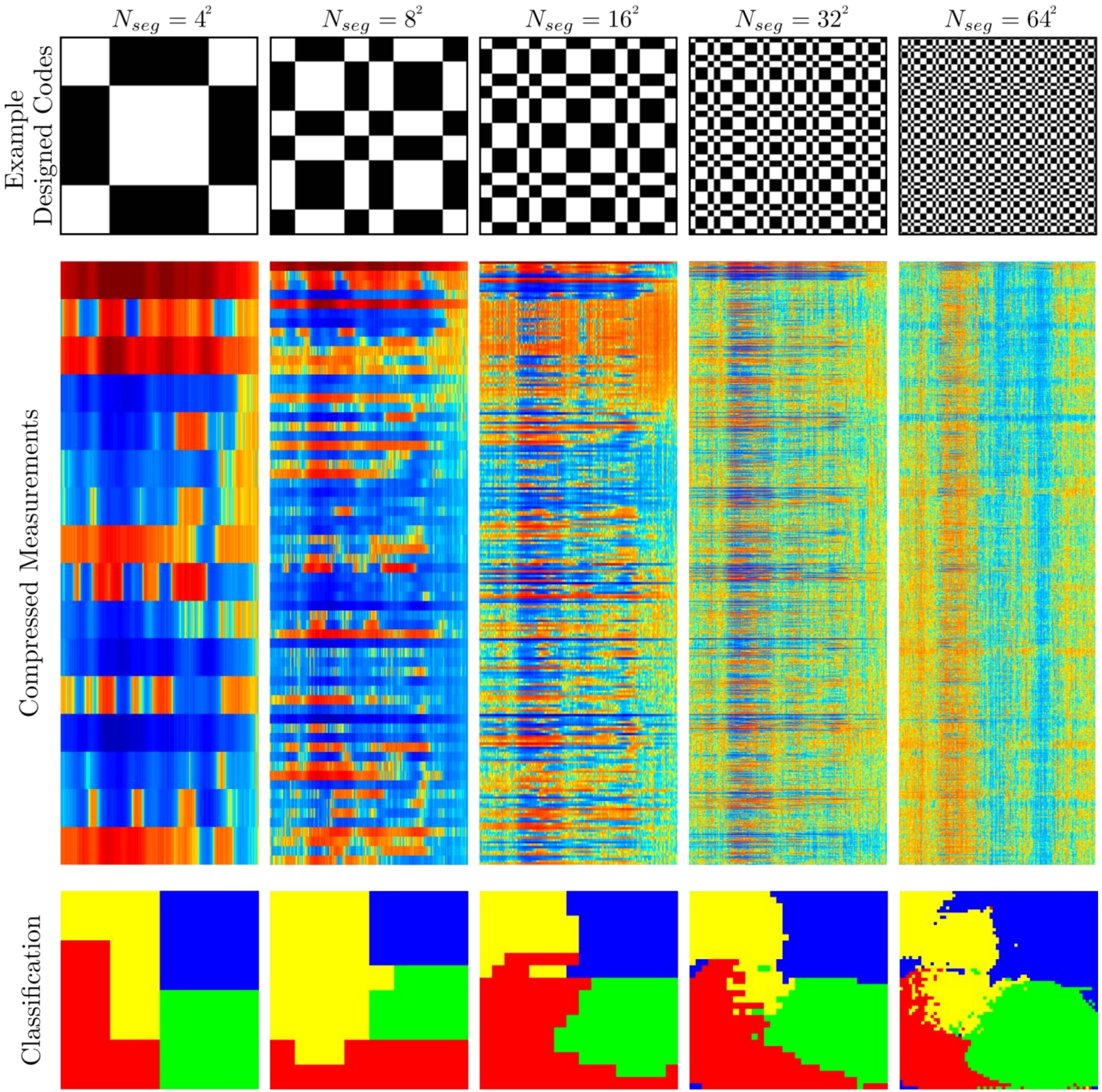
RGB composite acquired with a traditional camera

Experimentation

Ground truth



Final classification result via majority voting. OA: 85%



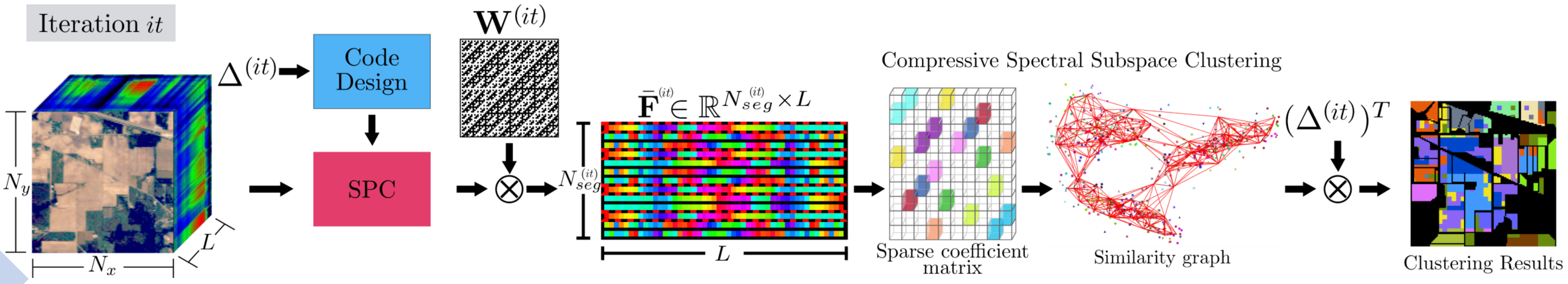
(a) OA: 81.90% (b) OA: 65.02% (c) OA: 83.83% (d) OA: 82.16% (e) OA: 79.42%

Conclusions

- The main contribution presented in this document is the alternative to spectral clustering in CSI measurements only using the NIR spectrum and excluding the information from the traditional visible range

- This work presented a sensing matrix designed to extract features directly from the compressed measurements in each stage of the hierarchical model.

- We demonstrate that the proposed imaging system, together with the sensing protocol and the computational algorithm, represents an efficient alternative to estimate clustering maps without requiring the full HIS recovery.



Thank You!

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SIS NIR

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Project Webpage