High-dynamic range CSI

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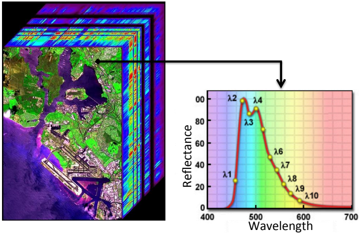
CoSeRa, 2015

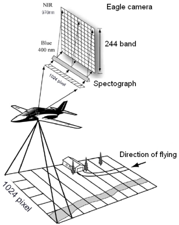
Outline

1. Compressive spectral imaging concepts
2. Sensor saturation problem
3. High-dynamic range method
4. Simulation results
5. Conclusions.

The Spectral Imaging Problem

Push broom spectral imaging: Expensive, low sensing speed, senses $N \times N \times L$ voxels.

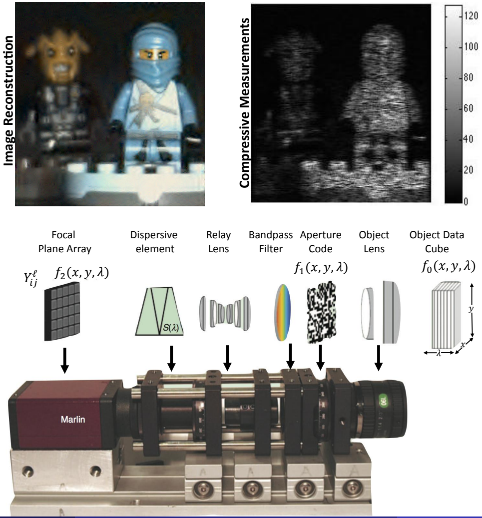




Tuneable Spectral Filter: Sequential sensing of $N \times N \times L$ voxels, limited by the number of colors.

Coded-Aperture Spectral Imaging (CASSI)

New compressive sensing method captures the datacube with a few snapshots.

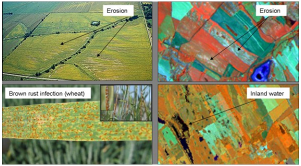


Why is this important?

Remote sensing and surveillance

Visible and near infra-red and a SWIR camera.

Devices are challenging in NIR and SWIR: cost, size, resolution and cooling.

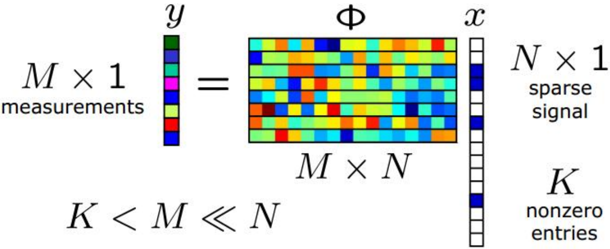


Remote sensing in agriculture.

Introduction

Compressive sensing introduced by [Candes, 2006], [Donoho, 2006], Tao, Romberg...

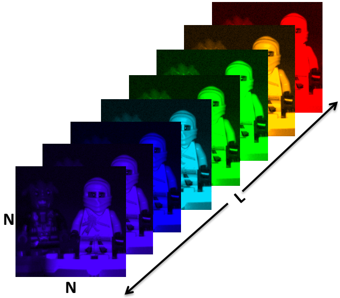
Measurements are given by $\mathbf{y} = \mathbf{\Phi x}$

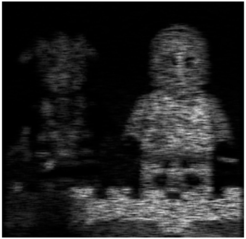


A sparse solution x is recovered from $\mathbf{y}$ by solving the inverse problem

$$\hat{\mathbf{x}} = \min_{\mathbf{x}} \|\mathbf{x}\|_1 \quad \text{s.t.} \quad y = \Phi \mathbf{x} \tag{1}$$

Introduction





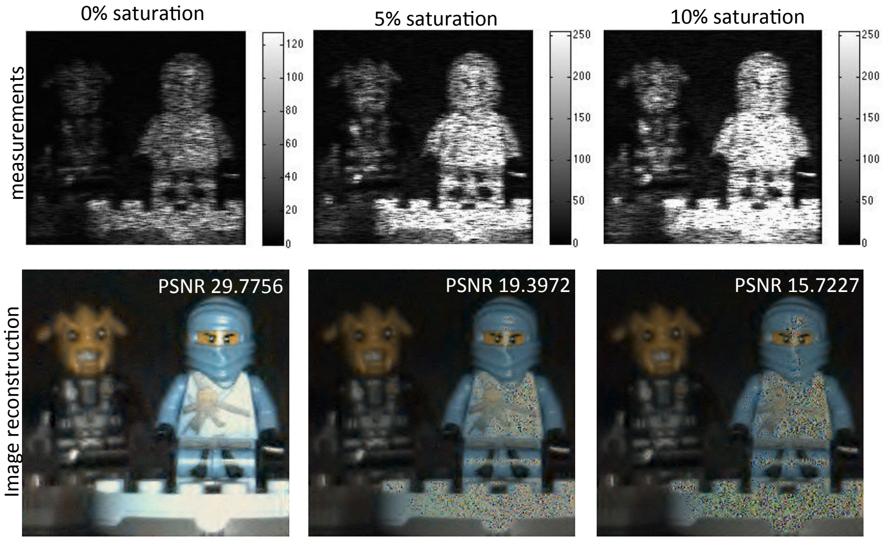
Data cube
$\mathbf{f} = \boldsymbol{\Psi}\theta$

Compressive Measurements
$\mathbf{g} = \mathbf{H}\boldsymbol{\Psi}\boldsymbol{\theta} + \mathbf{w}$

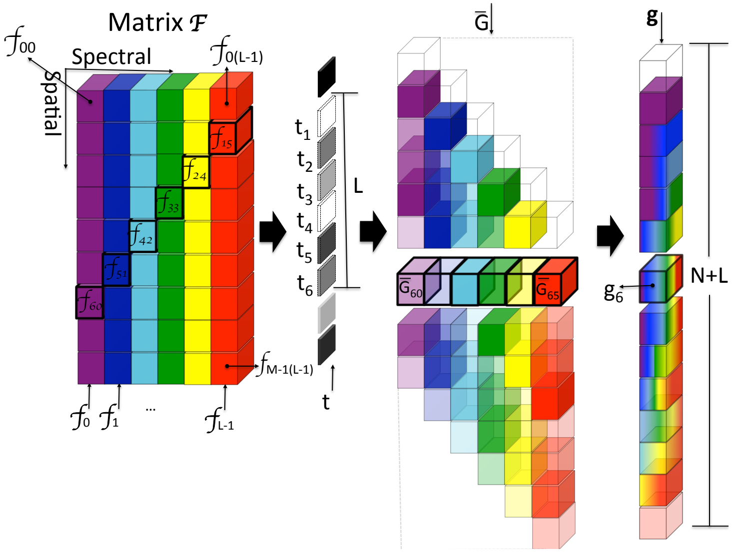
Undertermined system of equations

$$\hat{\mathbf{f}} = \boldsymbol{\Psi}(\underset{\theta}{\text{argmin}} \|\mathbf{y} - \mathbf{H}\boldsymbol{\Psi}\boldsymbol{\theta}\|_2 + \boldsymbol{\tau}\|\boldsymbol{\theta}\|_1)$$

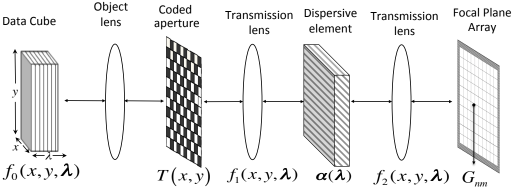
Saturated Measurements and Reconstructions



Sensor's Saturation

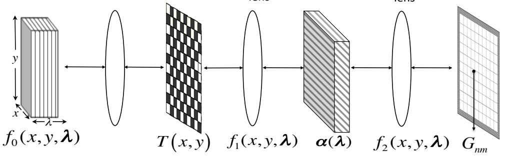


Proposed System

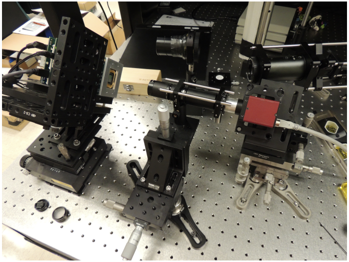


CASSI Sketch with Binary Coded Aperture

Proposed System

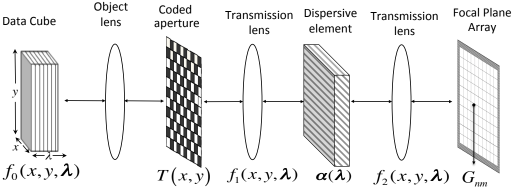


CASSI Sketch with Binary Coded Aperture



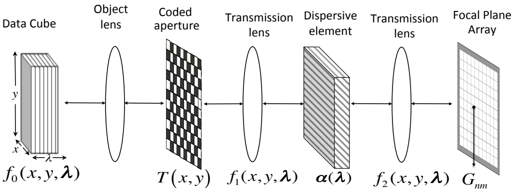
CASSI binary Coded Aperture implementation

Proposed System

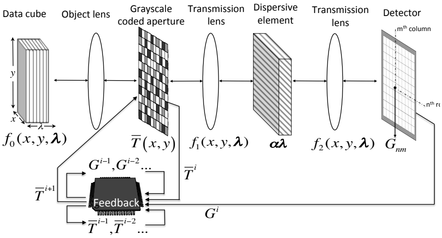


CASSI Sketch with Binary Coded Aperture

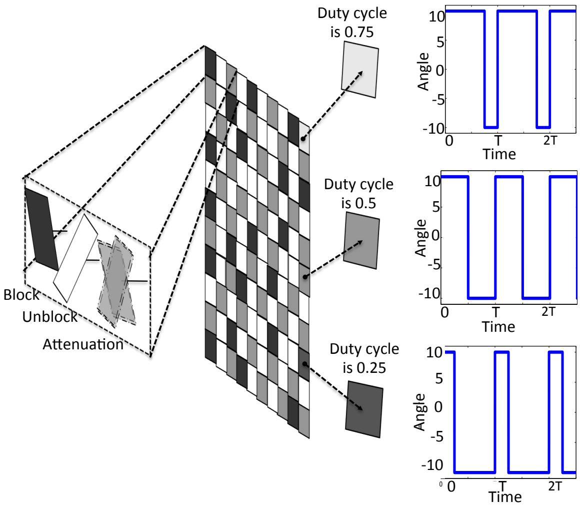
Proposed System



CASSI Sketch with Binary Coded Aperture

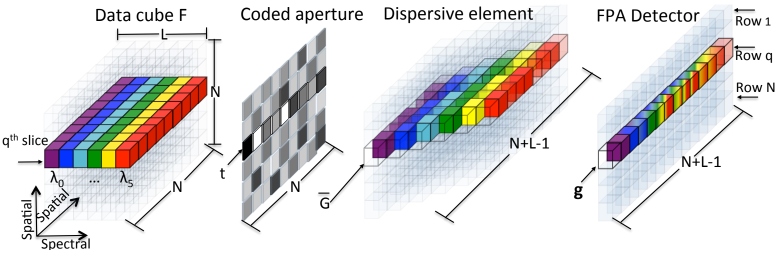


CASSI Sketch with Grayscale Coded Aperture



Adaptive Grayscale Coded Aperture and different values of Duty cycle

Data Cube Analysis by Rows



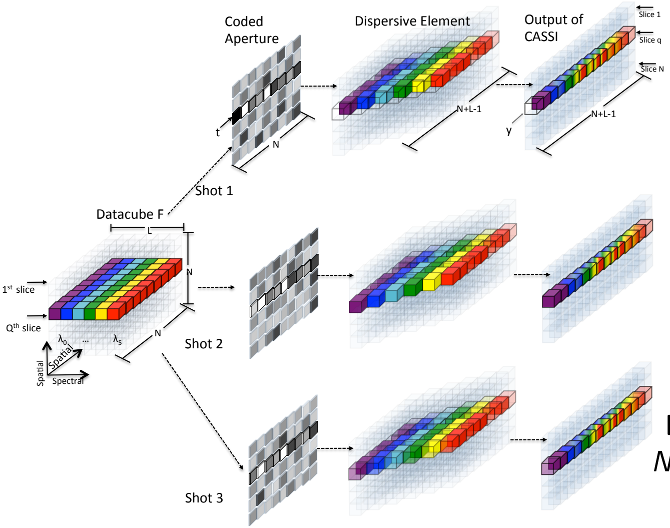
CASSI Sketch with Grayscale Coded Aperture

A single shot compressive measurement across the FPA:

$$G_{n,m} = \sum_{k=0}^{L-1} F_{(n-k),m,k} \hat{T}_{(n-k),m} + \omega_{n,m}.$$

1. F is the $N \times N \times L$ datacube.
2. $\hat{T}$ is the grayscale coded aperture.
3. ω is the sensing noise.

CASSI Multishot Matrix Model



$$\begin{bmatrix} \mathbf{g}^0 \\ \mathbf{g}^1 \\ \vdots \\ \mathbf{g}^2 \end{bmatrix} = \begin{bmatrix} \mathbf{H}^0 \\ \mathbf{H}^1 \\ \vdots \\ \mathbf{H}^2 \end{bmatrix} \begin{bmatrix} \mathbf{f} \end{bmatrix}$$

$\mathbf{g} = \mathbf{H}\mathbf{f} + \mathbf{w}$ Where $\mathbf{H} \in \{0,1\}$ with size $N(N+L-1) \times (N \cdot N \cdot L)$

Computational Model to Reduce Saturation

V is a counter computed in real time from compressive measurements:

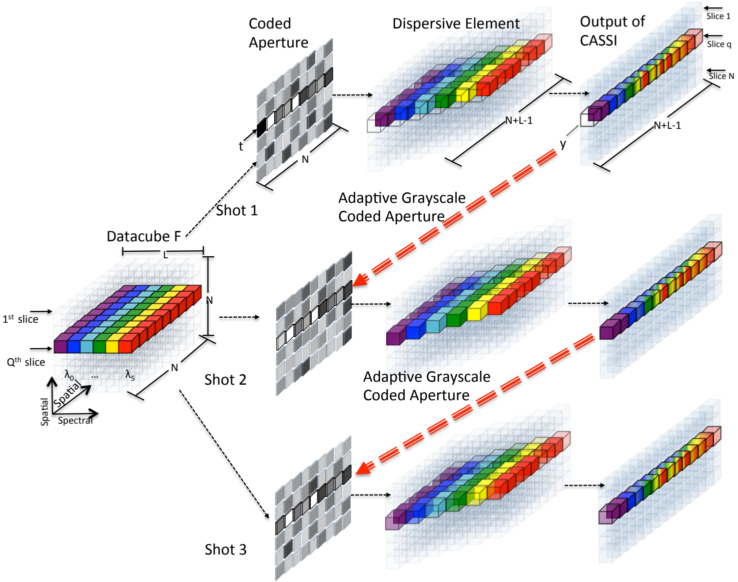
$$V_{n,m}^{i} = \sum_{\ell=n-(L-1)}^{n} u[G_{\ell,m}^{i} - s] + 1,$$

$$W_{n,m}^{i} = \left(\frac{1}{V_{n,m}^{i}}\right) \cdot \left(\frac{1}{V_{n,m}^{i-1}}\right),$$

$$\hat{\mathbf{T}}^{i+1} = \mathbf{T}^{i+1} \circ \mathbf{W}^{i},$$

1. **V** weight matrix with dimensions $N \times N$.
2. $u[.]$ is the Unit step function
3. $s = 2^{b} - 1$ represents the saturation level of the sensor
4. **W** attenuation matrix is the penalization function

Grayscale Adaptive Coded Aperture

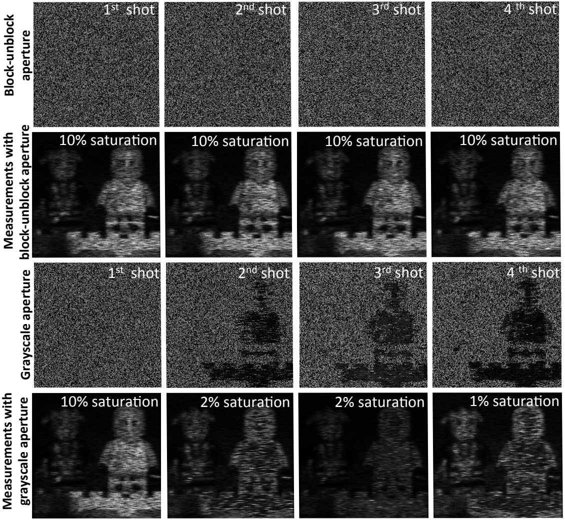


Simulation: Database used

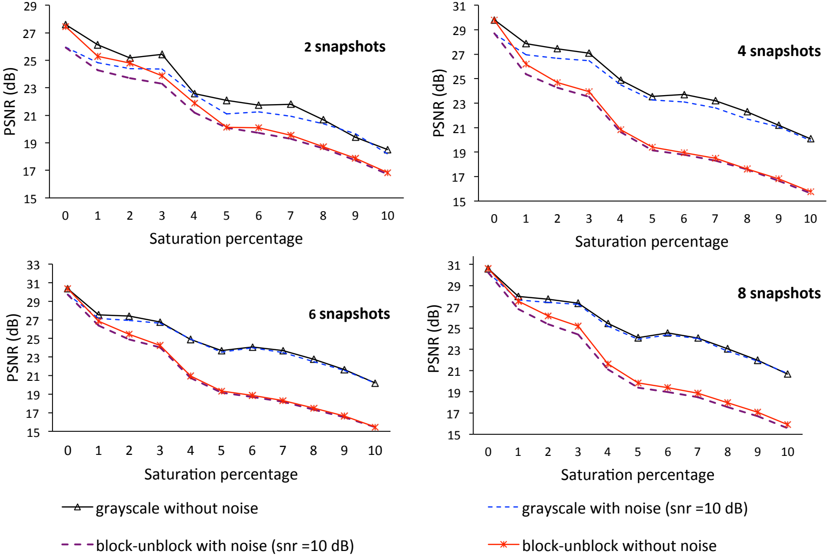
Database obteined using a wide-band Xenon lamp as the light source, a visible mochromator (450nm and 650nm). The image intensity was captured using a CCD camera exhibiting 256×256 pixels.

Compressive Measurements and Saturation

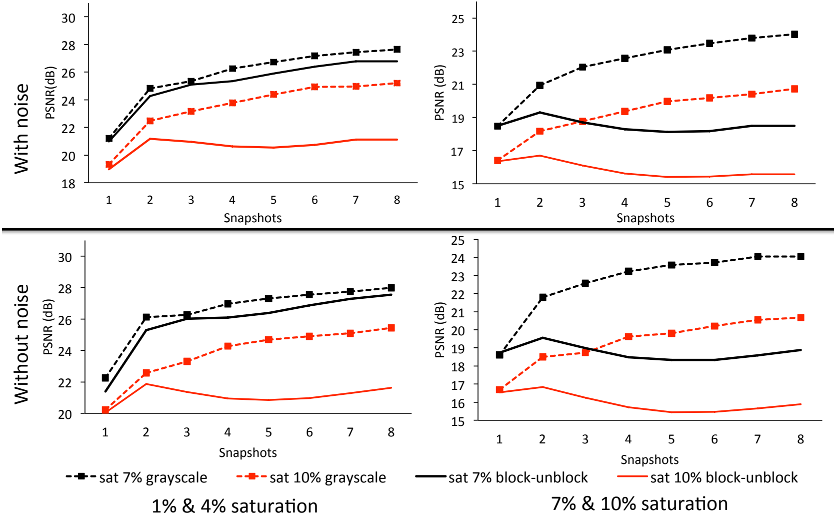
Saturation reduces as snapshots increase.



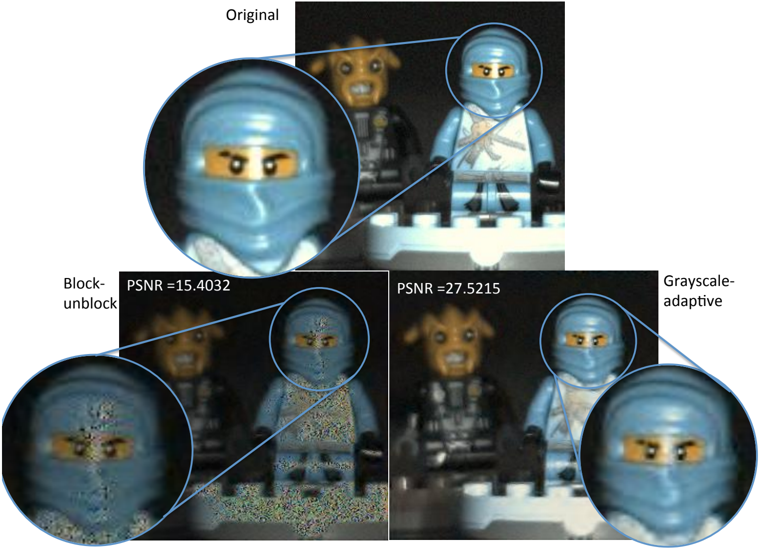
Quality of Reconstruction vs Saturation Percentage



Quality of Reconstruction vs Snapshot

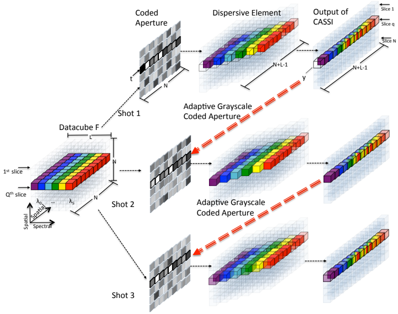


Binary vs Adaptive Grayscale Reconstructions



Conclusions

1. Grayscale adaptive coded apertures have been introduced in CASSI system to replace the traditional block-unblock coded apertures.
2. The proposed architecture permits to attenuate the effect of the saturation of the FPA sensors.
3. The designed grayscale coded apertures outperform the block-unblock coded apertures in up to 5 dB in the quality of the reconstructed images.



¡Grazie mille!