Fraunhofer Institute of Optronics, System Technologies and Image Exploitation IOSB

Compressive sensing imaging through atmospheric turbulence

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Karlsruhe


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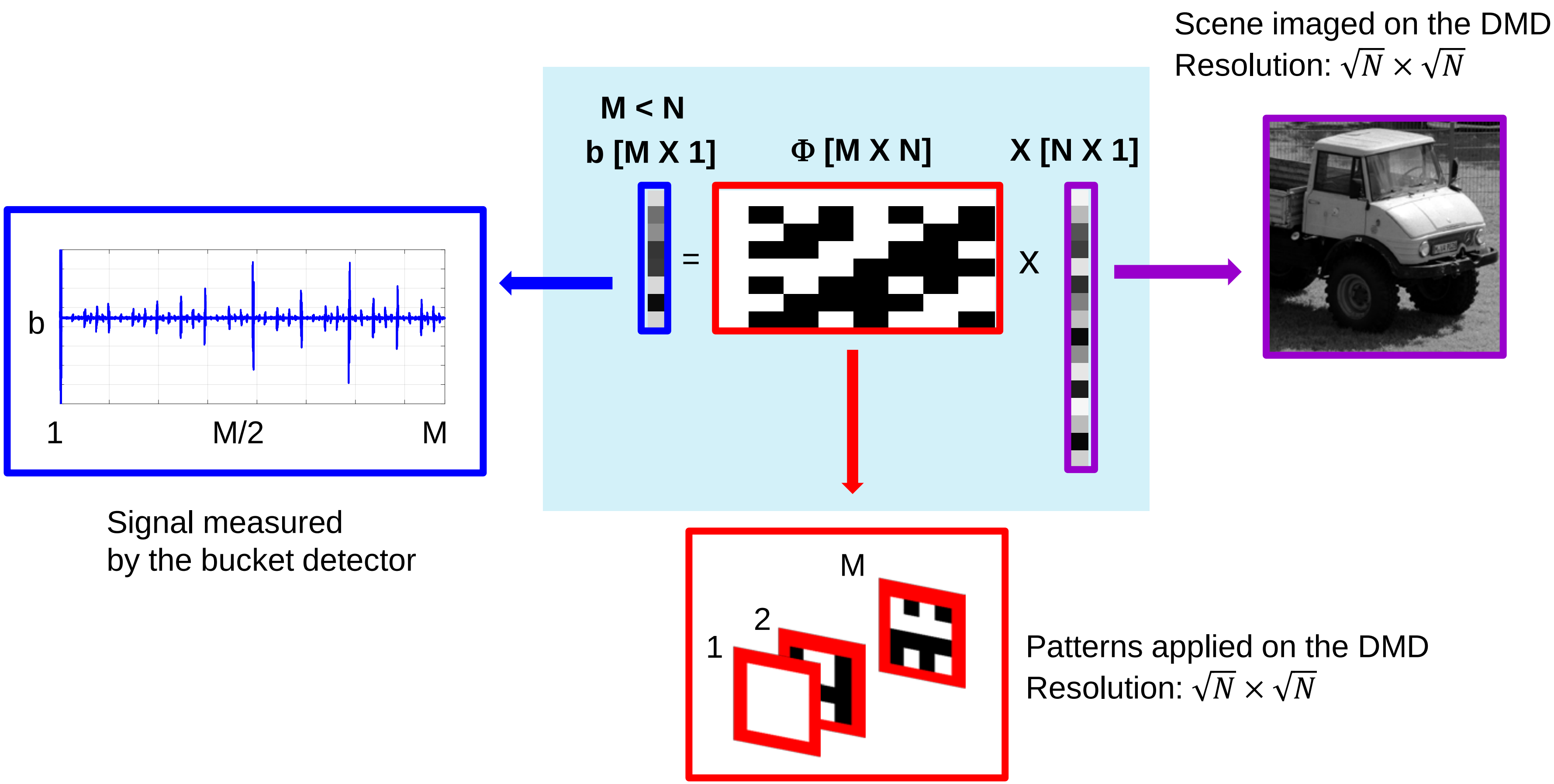
Motivation

- The technique allows the reconstruction of a high resolution image using data acquired with a lower resolution sensor
- Number of acquirements < image resolution

- To expand further spectral ranges for applications as e.g. gated viewing and 3D imaging sensors
- To surrogate expensive 2D detector arrays

- FPA-images through turbulence degrades due to intensity fluctuation, distortion, and blur, notably for long-range applications
- The sensitivity of CS imaging techniques to atmospheric turbulence has not been rigorously investigated so far
- To date, no comparative study on the turbulence influence on both types of systems is available

Compressed sensing measurement



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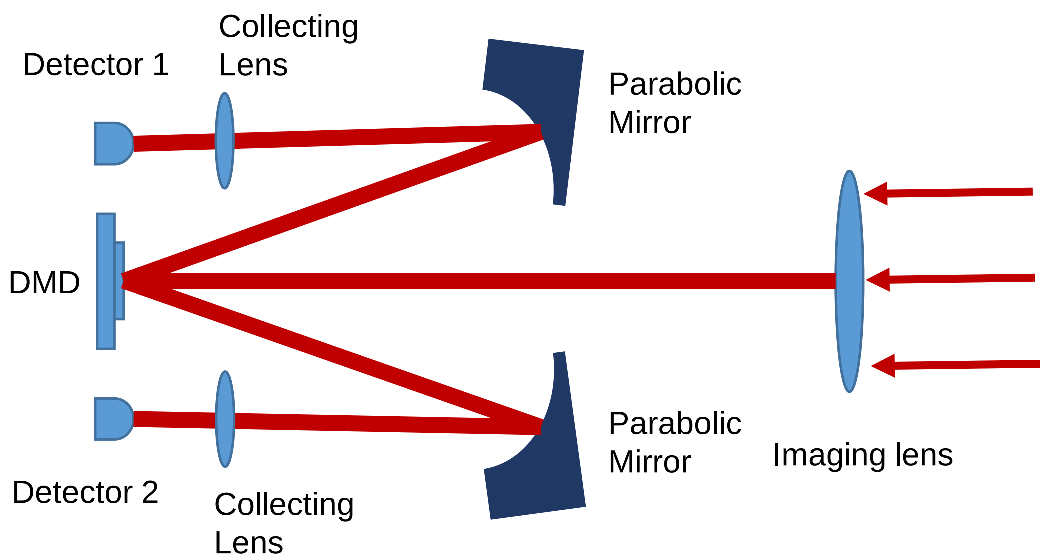
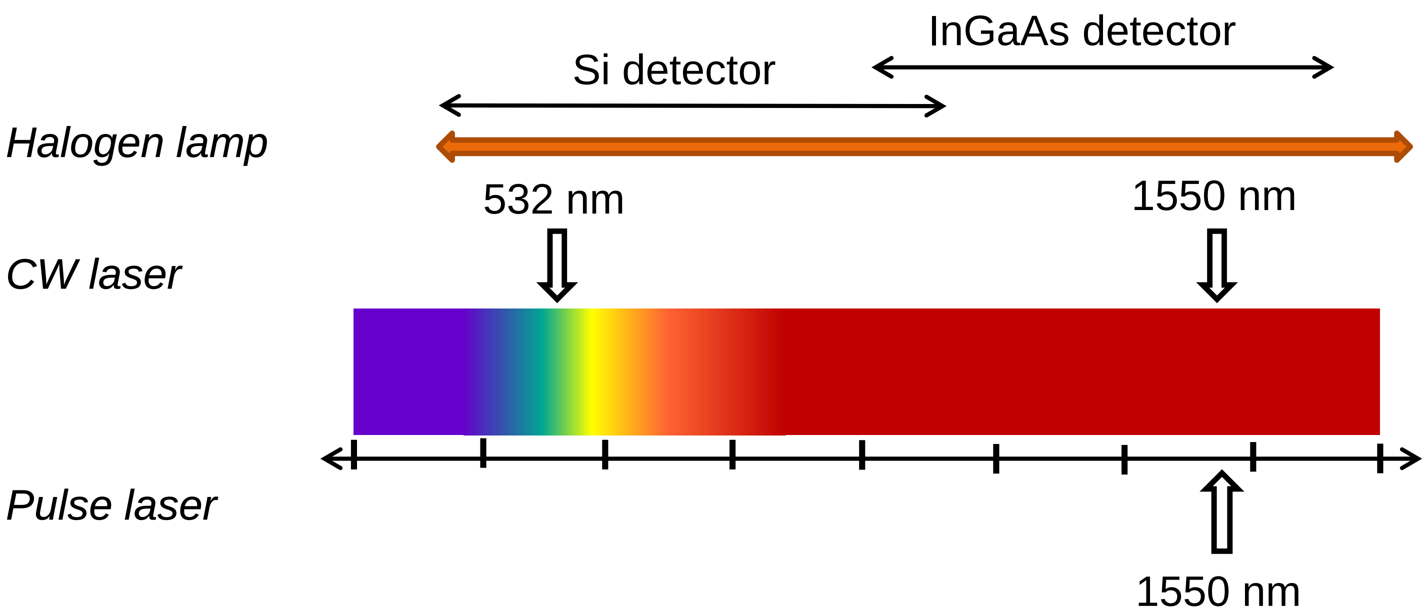
Experimental setup

Simultaneously acquisition of complementary patterns modulated signal:

- *Sum of the two signals used for intensity variation correction*
- *Improvement of image reconstruction*
- *Background light correction*
- *Multispectral imaging e.g. VIS and SWIR*



Illumination sources and detectors



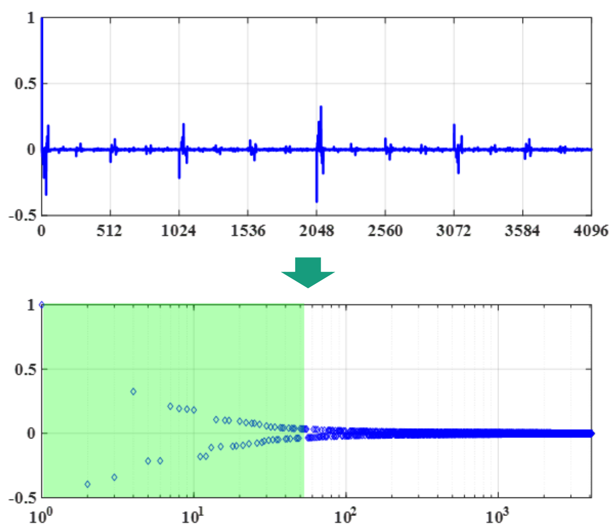
Light source	Detector	Overlap spectral range
Halogen lamp	Si photodiode	VIS: 350 – 1100 nm
Halogen lamp	InGaAs photodiode	SWIR: 800 – 1700 nm
CW laser	Si photodiode	VIS: 532 nm
CW laser	InGaAs photodiode	SWIR: 1550 nm
Pulse laser	InGaAs photodiode	SWIR: 1550 nm

Pattern selection

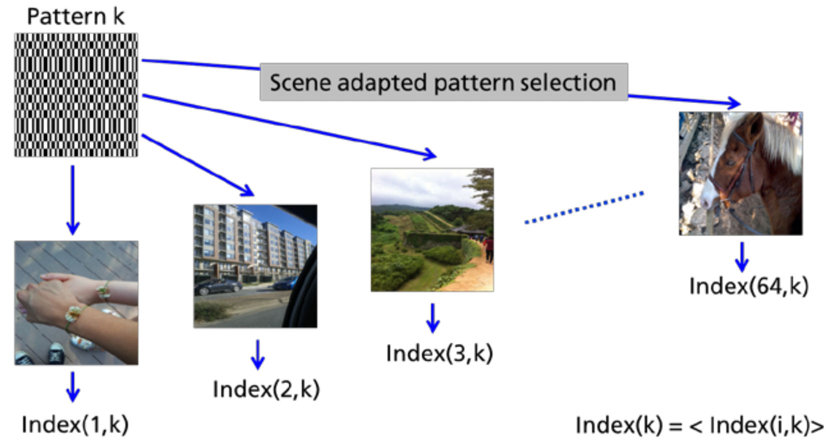
M patterns based on Hadamard matrix are selected using different methods:

A: Sequency ordered patterns
B: Scene adapted pattern selection
C: Image collection relevant patterns
D: Number of blocks ordered patterns

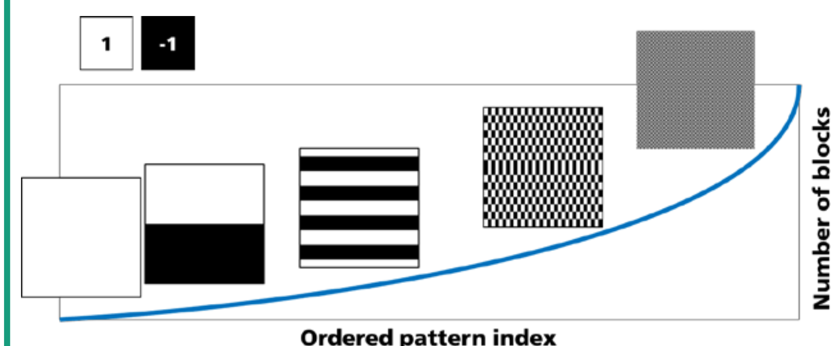
B: Scene adapted pattern selection



C: Image collection relevant patterns



D: Number of blocks ordered patterns



SWIR images acquired with pulse laser illumination

- Reconstructions: 256 x 256 pixels
- Scene adapted pattern selection
- Pulse illumination: 1550 nm, 10 ns, 4 µJ

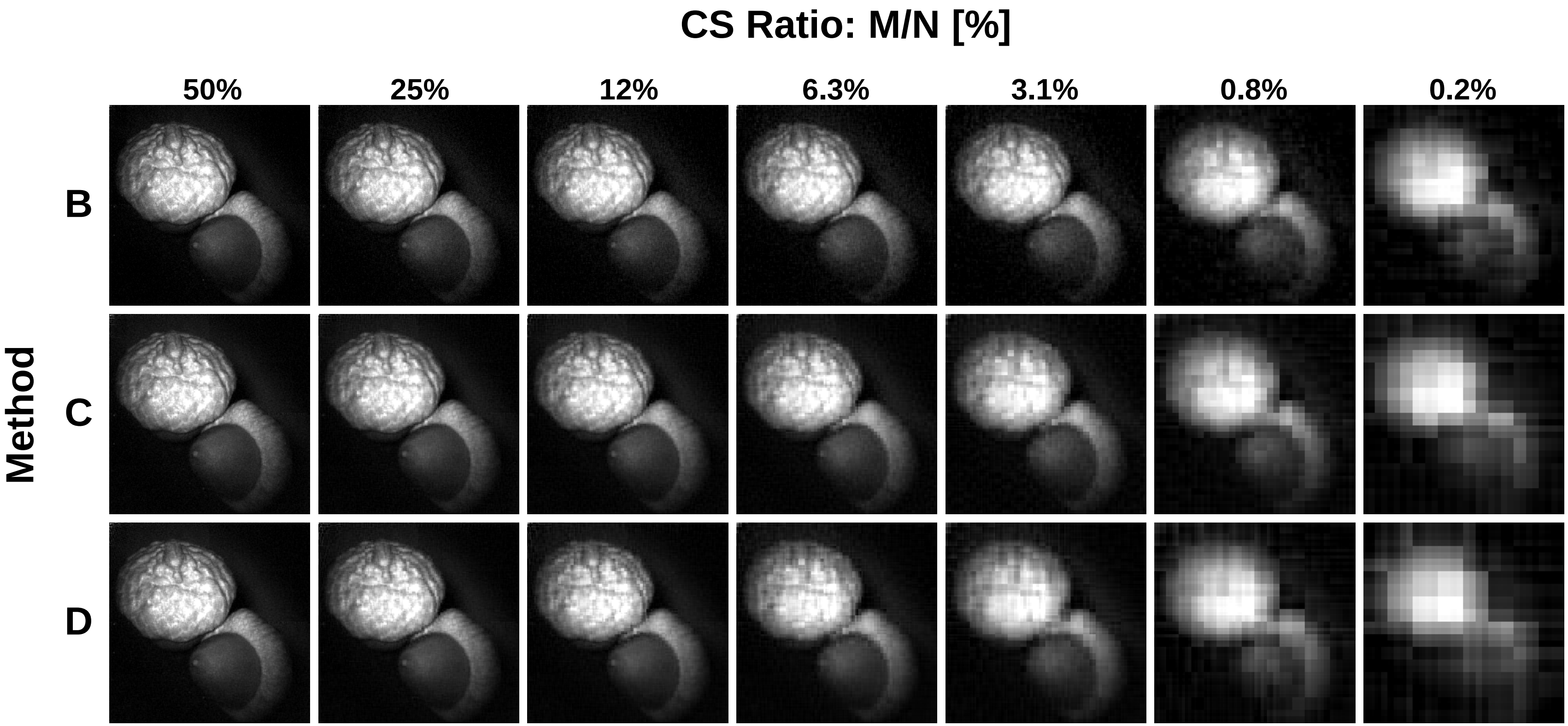


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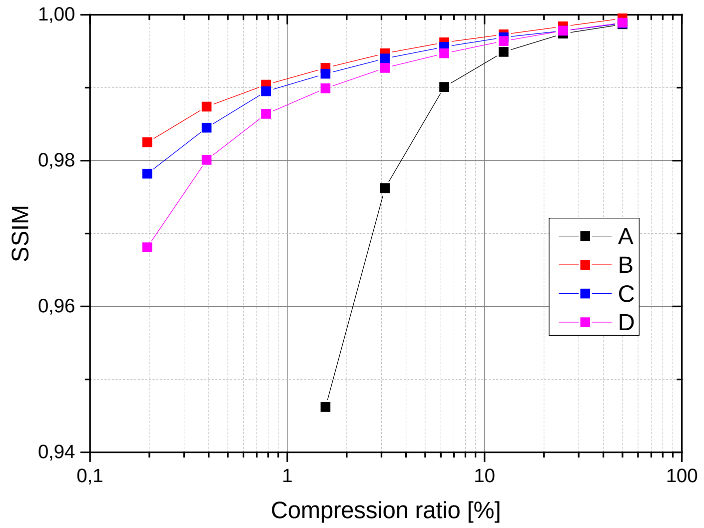
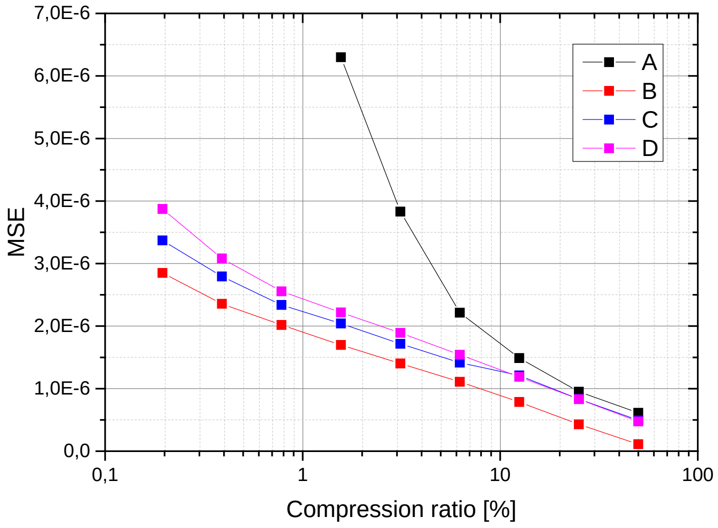
Image quality metrics

Structural Similarity Index



Mean Square Error



A: Sequency ordered patterns
B: Scene adapted pattern selection
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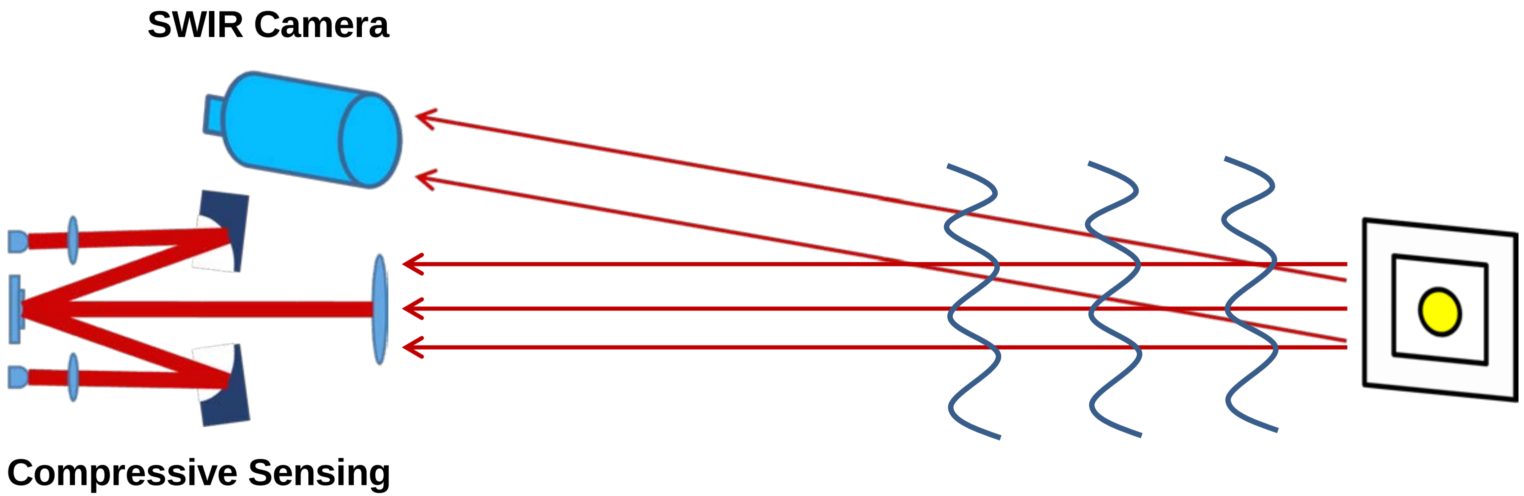
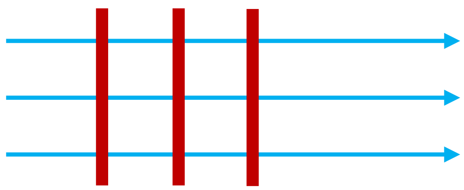
Experiments through turbulence

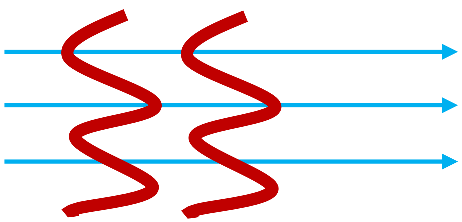


	Compressive Sensing	SWIR Camera
Detector	InGaAs single element (2x)	InGaAs - FPA
Resolution	256 x 256	640 x 512 (256 x 256 used)
Pixel Size	41.1 µm (3 x 3 micromirrors pro pixel)	25 µm
Optics	600 mm F/6	400 mm F/4
IFOV	68.5 mrad	62.5 mrad

CS imaging through turbulence

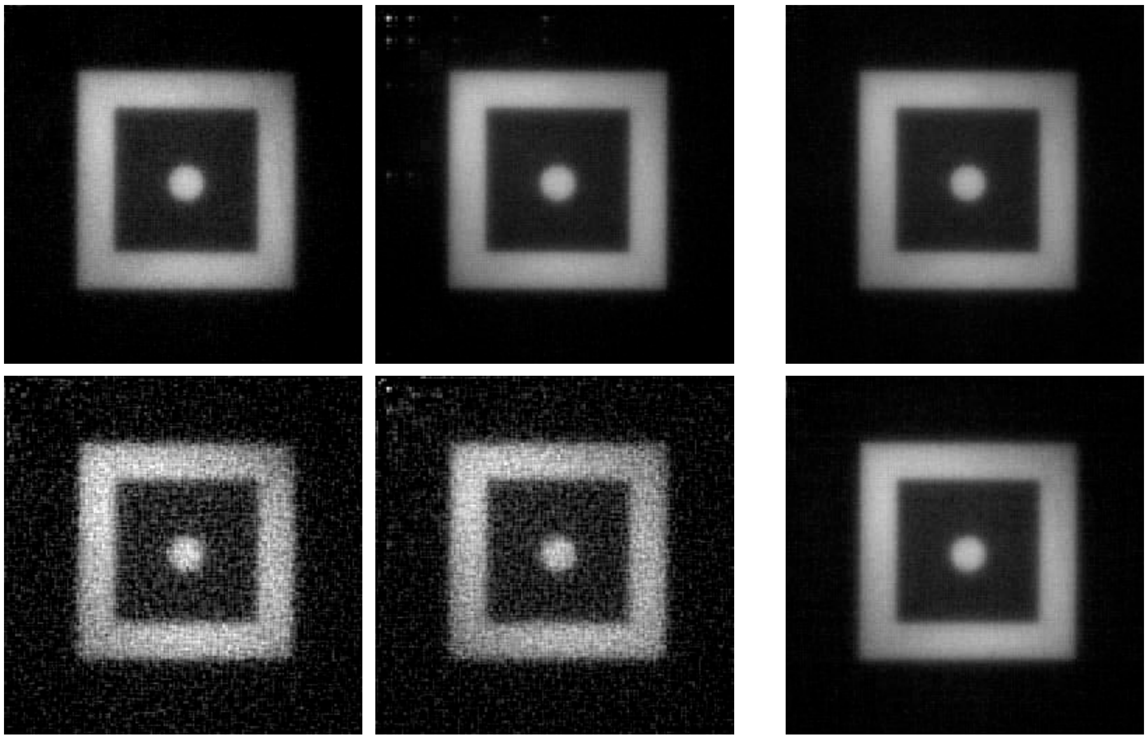


Normal atmosphere

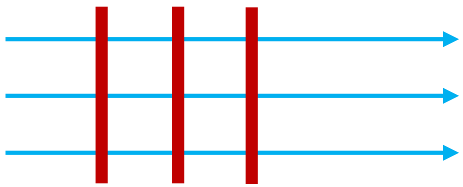


Strong turbulence

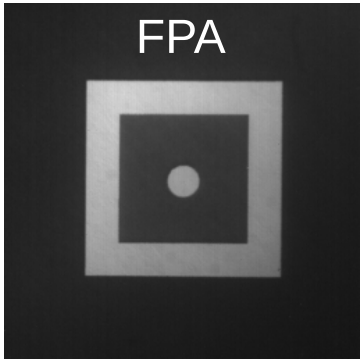
Channel 1 | Channel 2 | Channels Diferrence

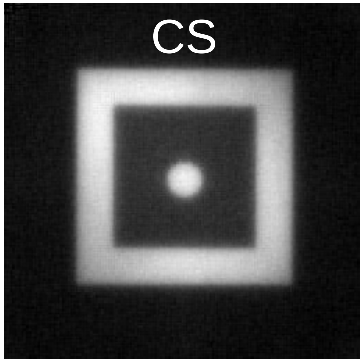


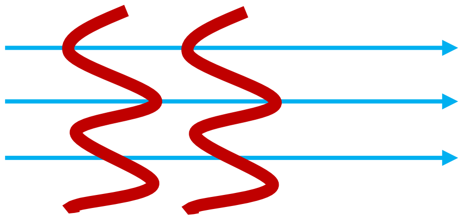
Comparison FPA – CS under strong turbulence



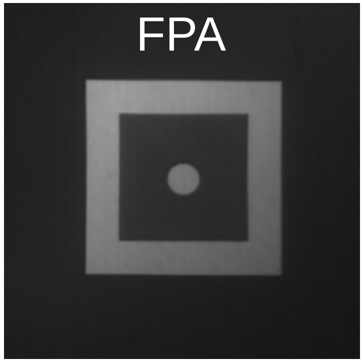
Normal atmosphere

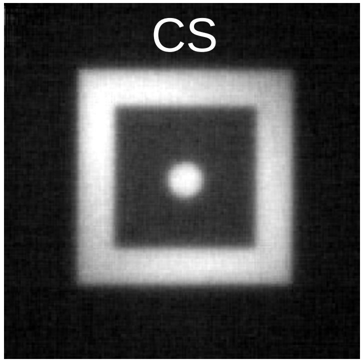






Strong turbulence





Data fitting

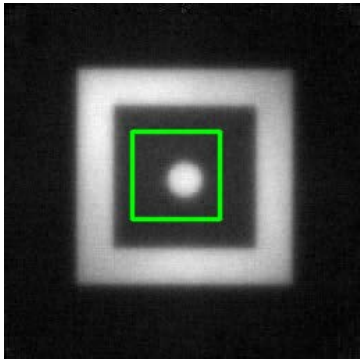
$$I_{circle}(x,y) = c_{background} + c_{circle} \cdot sigmoid\left(s, \sqrt{(x-x_0)^2 + (y-y_0)^2}, r_0\right)$$

r_0 – radius of the circle

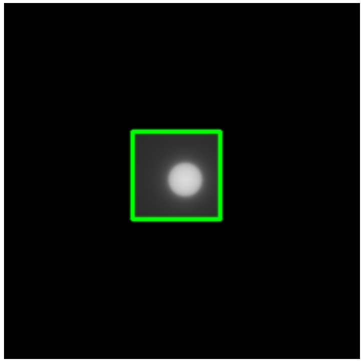
x_0 , y_0 –center of the circle coordinates

s – sharpness parameter

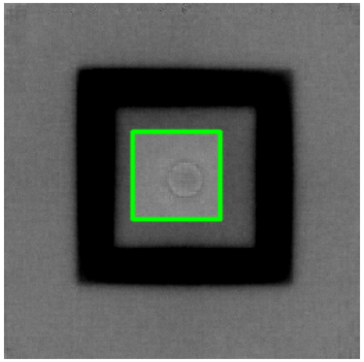
$$Fluctuations = IFOV \times \sqrt{std(x_0)^2 + std(y_0)^2}$$



$I(x_i, y_i)$

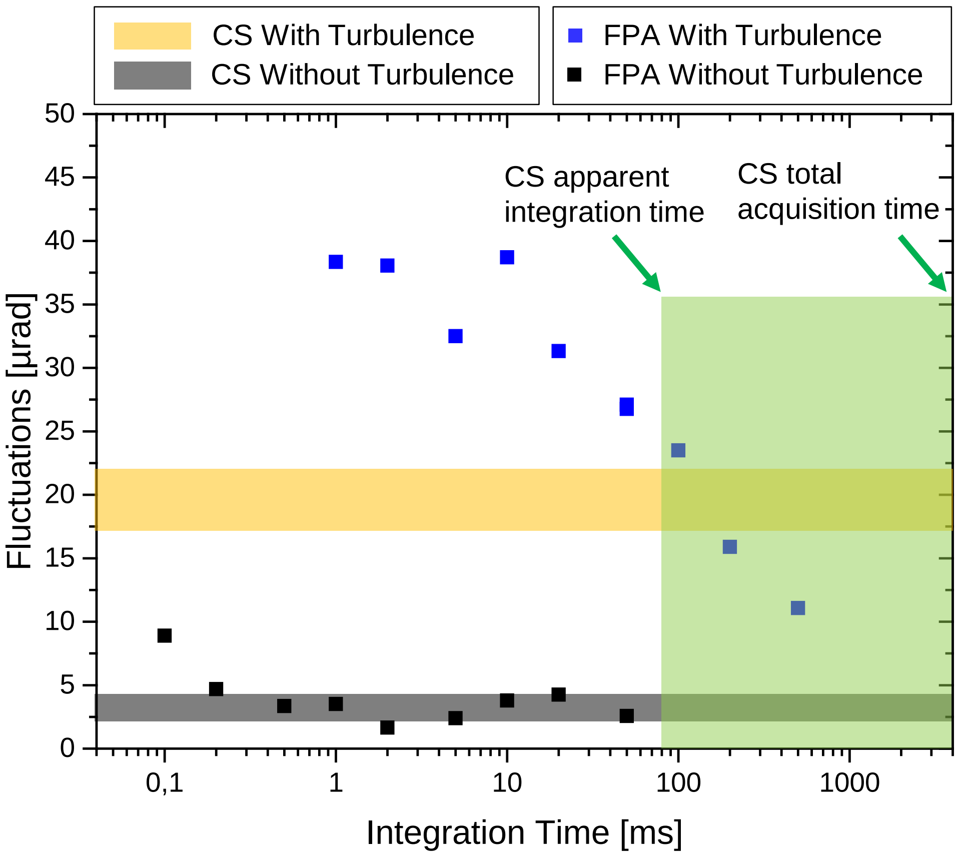


$I_{circle}(x_i, y_i)$



$I(x_i, y_i) - I_{circle}(x_i, y_i)$

Evaluation of position fluctuations



Aparent integration time: Number of patterns × Integration time / pattern

Total acquisition time: Number of patterns × DMD frame rate

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Summary

- Compressive sensing measurements have been performed in SWIR and VIS range - non-coherent and coherent illumination (cw and pulse)
- Four different methods have been applied and compared to select the encoding pattern based on Hadamard matrix
- Turbulence influence on a SWIR CS imaging was investigated in comparison to an InGaAs-FPA based camera
- The measurements showed that the CS reconstructed images experience similar turbulence-induced effects like the FPA-based camera
- The experiments performed **so far** could not demonstrate an advantage for one of the two image acquisition concepts