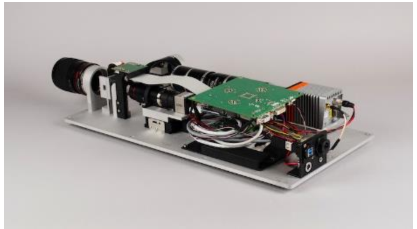
Compact Multi-Spectral Imager for Nanosatellites II

CEOI 11th Call

http://cmsin.phys.strath.ac.uk/



Project Lead: Dr Daniel Oi
Computational Nonlinear & Quantum Optics
SUPA Department of Physics

NCEO/CEOI Conference 24th June 2020

Compact Multi-Spectral Pushframe Camera for Nano-Satellites
Y Noblet, S Bennett, P F Griffin, P Murray, S Marshall, W Roga, J Jeffers, D Oi
https://arxiv.org/abs/2006.01653

Talk Outline

University of Strathclyde Science

- Single Pixel Imaging
- Pushframe Imaging
- Experimental Demonstration
- Prototype
- Future Work

department of physics at the university of strathclyde

Scottish Centre of Excellence in Satellite Applications

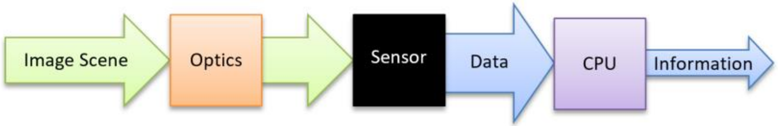
Centre for Signal & Image Processing (CeSIP)

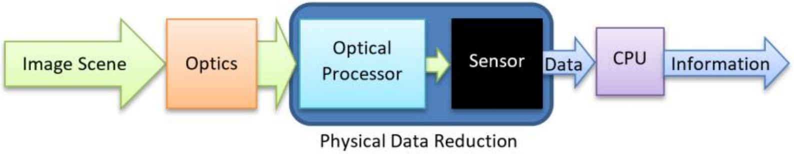
wideblue making technology happen

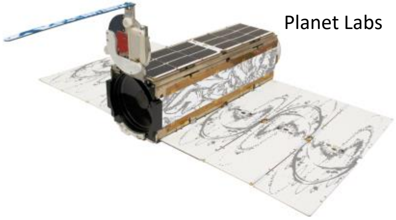
- Physics
  - **Daniel Oi:** Project Manager
  - **John Jeffers:** Lead Manager on Design & Simulation
  - **Paul Griffin:** Lead Manager on Experiment
  - **Yoann Noblet:** Experimental Optics
  - **Wojciech Roga:** Former member, theory
- SoXSA
  - **Malcolm Macdonald:** Lead Manager Roadmapping
  - **Steve Owens:** User Engagement, Mission Analysis
- CeSIP
  - **Steve Marshall:** Lead Manager Signal Processing
  - **Paul Murray:** Co-Manager Signal Processing
  - **Stuart Bennett:** Signal and Image Processing
- WideBlue
  - **Barry Warden:** Project Manager
  - **Craig Whitehill:** Optical Physicist
  - **Callum Stewart:** Mechanical Engineer
  - **Graeme Millar:** Electronics design engineer
  - **Ken Devlin:** Software / Firmware design
  - **Niall Slater:** Mechanical Engineer

Objective

- Target detection, characterisation
  - *Complement* traditional imaging
  - *Reduced* data acquisition
  - “*Intelligent* Sensing”
- Optimised for smallsat constellations
  - Low power requirements
  - Persistent operation
  - Cueing of other orbital assets
- Flexible operational modes
  - Adaptive/event driven
  - Multispectral operation

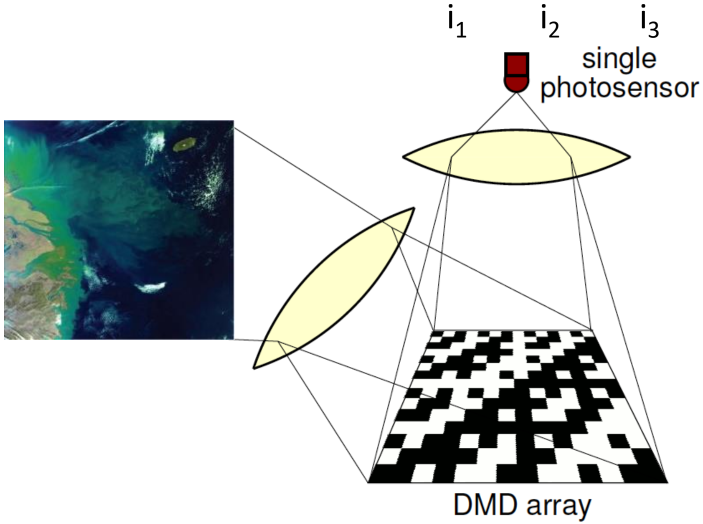






Single-Pixel Imaging (SPI)

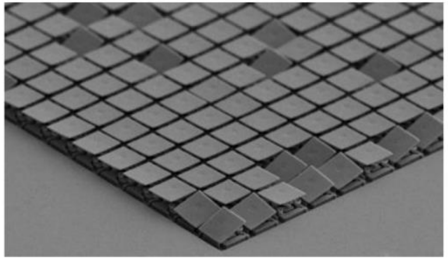
- Multiplexed/modulated spatial information captured by single pixel, *multiple patterns*
- Hadamard Patterns or Compressive Sensing (CS)/Sparse Reconstruction
- Imaging at λ where 2D arrays unavailable or expensive
- Foveated or adaptive sampling

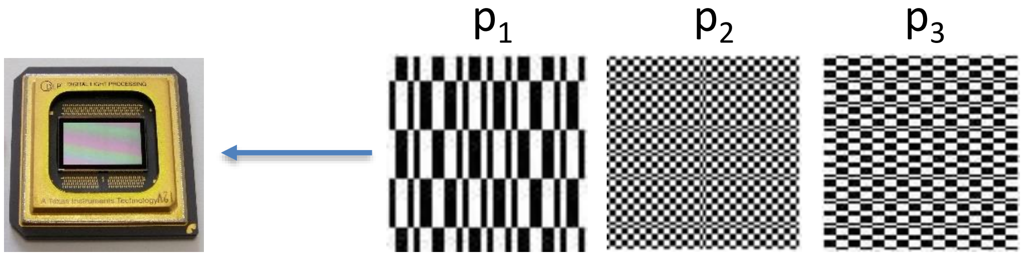


Digital Micromirror Device
Optical processor

Reflective – Inherently broadband

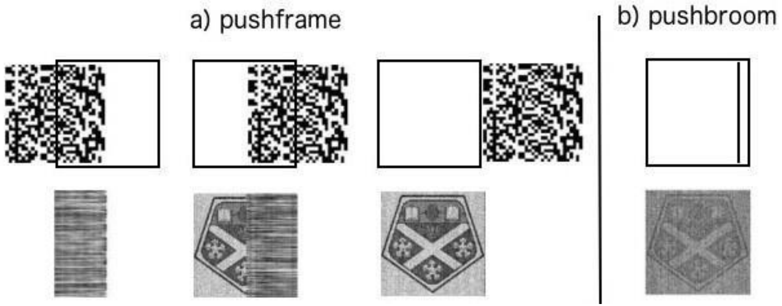
All bands automatically co-registered

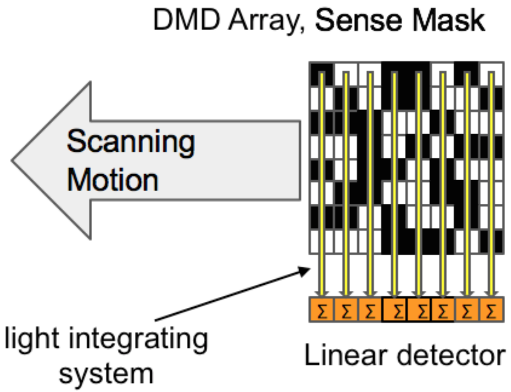


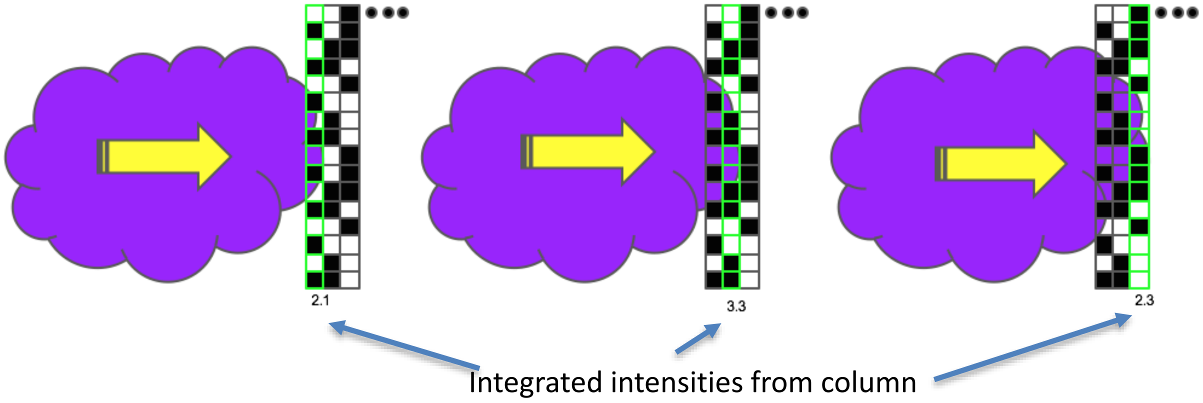


Pushframe Imaging

- Overcomes sampling time limitation of conventional SPI
- Similar to Pushbroom operation
- Parallelised 1D Single Pixel Imagers
- Can use a fixed pattern, *motion across scene* applies different patterns to each strip automatically
- Advantages
  - Enables *Compressive Sensing*
  - *Adaptive Operation*
  - *SNR Improvement* for certain noise (c.f. Hadamard Transform Spectrometry), particularly when read-noise limited

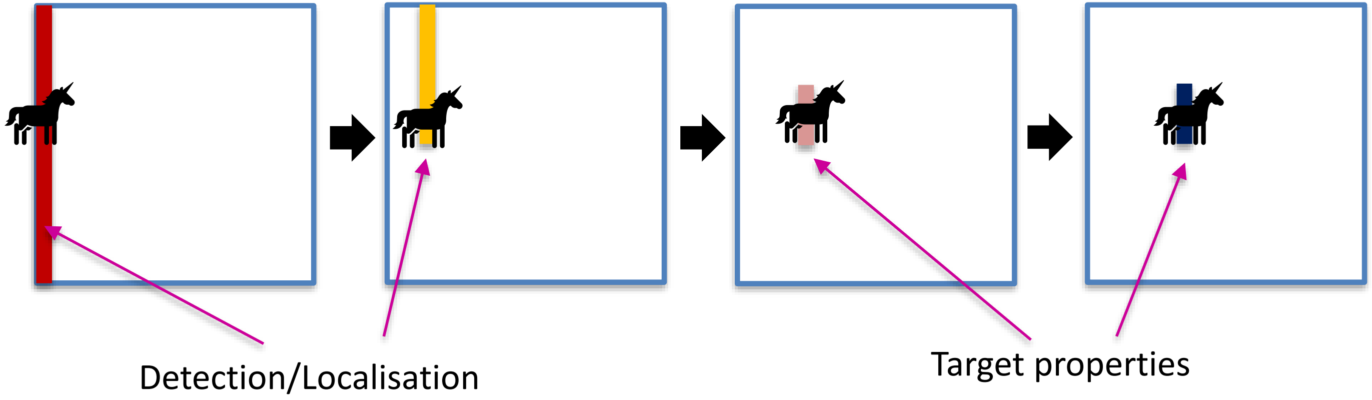






Adaptive Sampling

Reduced data acquisition, low power monitoring



Sense patterns adaptively chosen based on preceding “signatures”

Patterns can also mask out land/sea, reduce background light

Simulated pushframe imaging with adaptive sense patterns

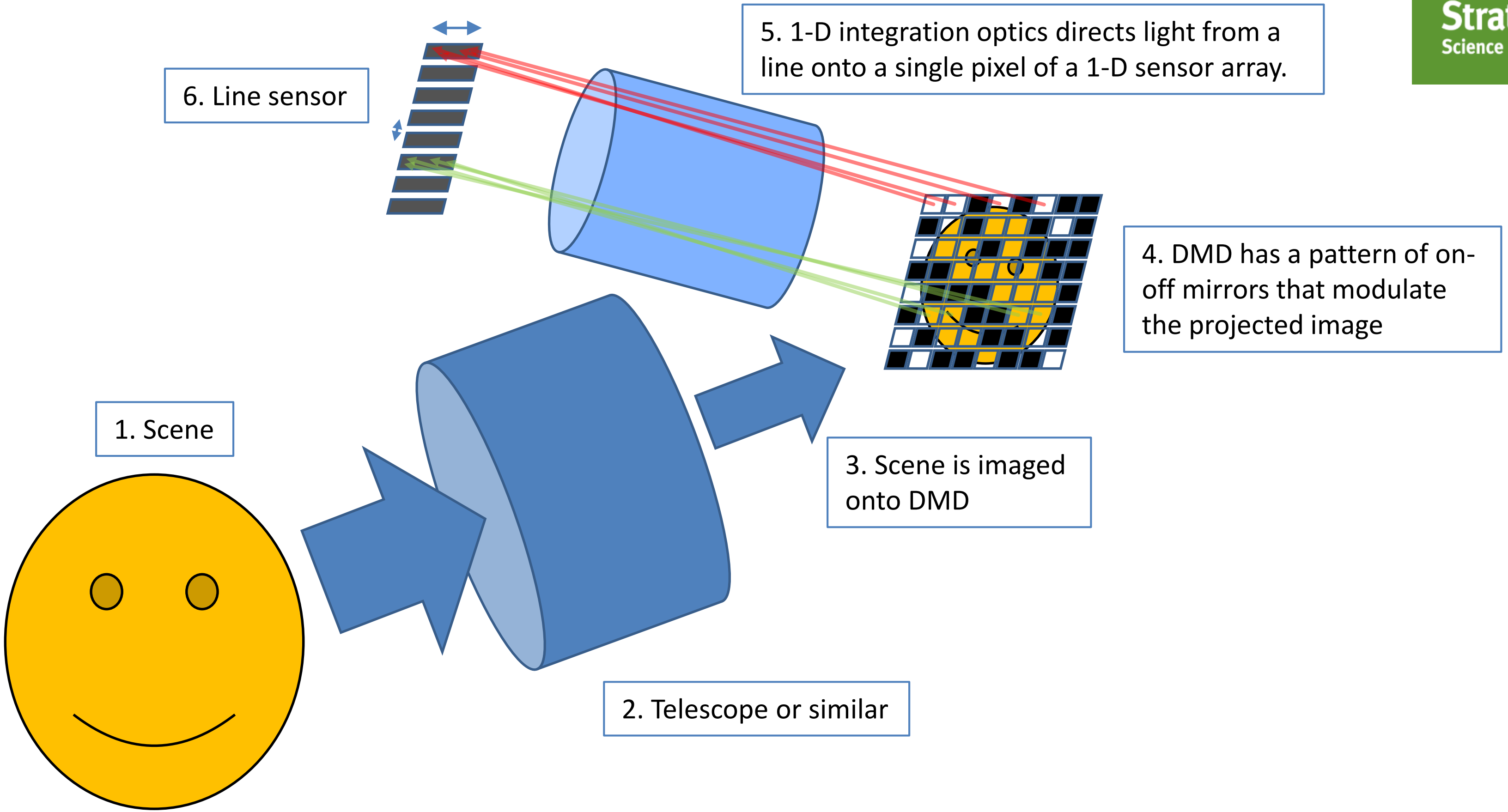
(a) Monochrome source image

(b) Acquired image, 2.3% of source

(c) Multi-spectral source image

(d) Acquired image, 1.5% of source

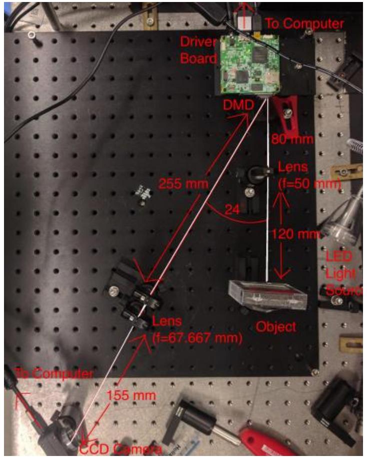
Imaging Concept



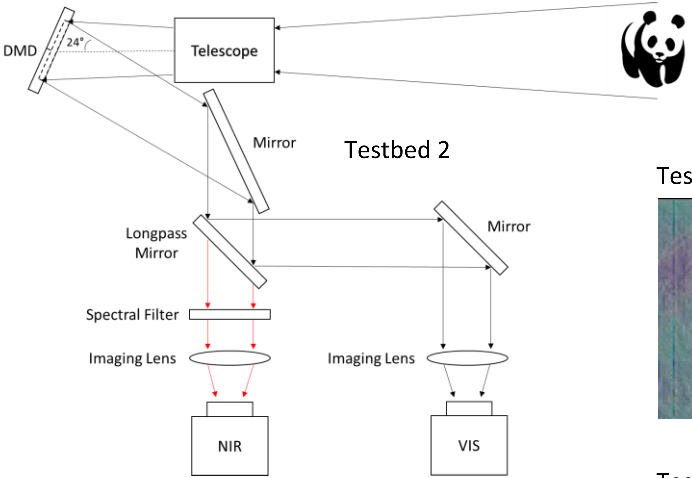
Experiment

Note: 1D Light Integration Optics

- Difficult to design and construct
- Simulated by post-processing 2D array, allows analysis and diagnostics
- Novel optical configuration required for practicality



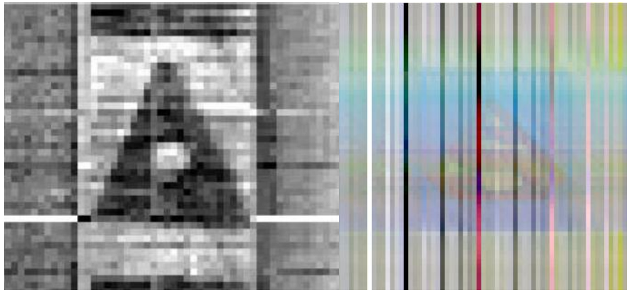
Testbed 1



Testbed 2

Testbed 2 Results

Testbed 3 Results



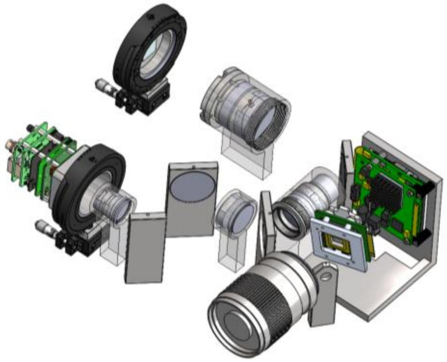
Testbed 1 Early Results

Prototype

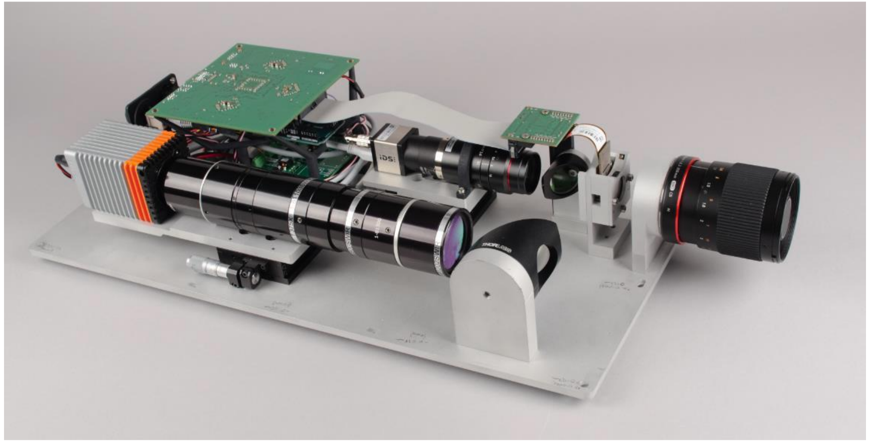
wideblue
making technology happen

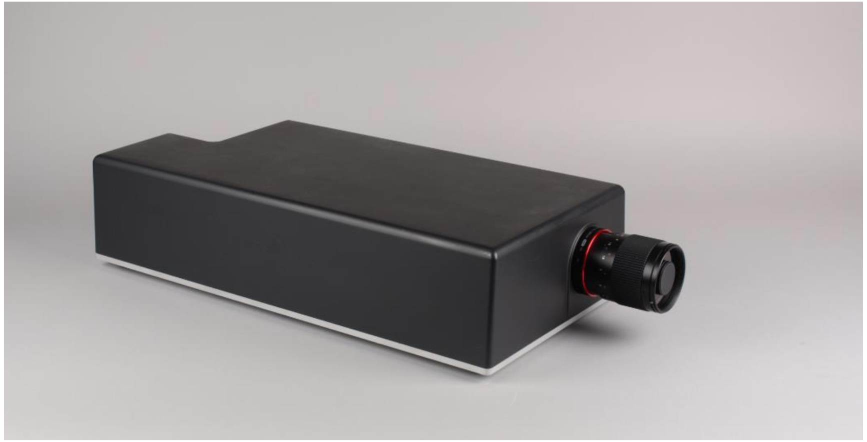
University of Strathclyde Science

- Engineering Model, first pass at packaging of optics and electronics
- COTS components mostly
- Vis (RGB) and SWIR, simulated 1D optical integration
- “Field deployable”, in situ testing



Early optical layout design. Repackaged for ease of manufacture





CS Pushframe

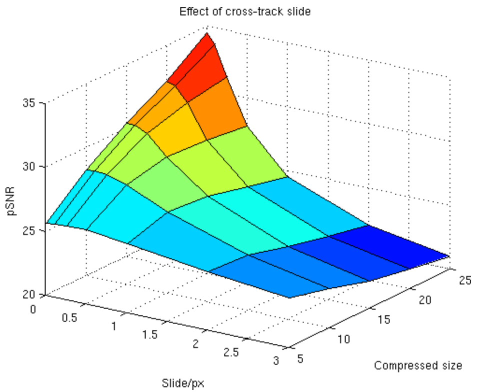
Compressive Sensing to reduce acquisition time, onboard data handling, and transmission requirements.

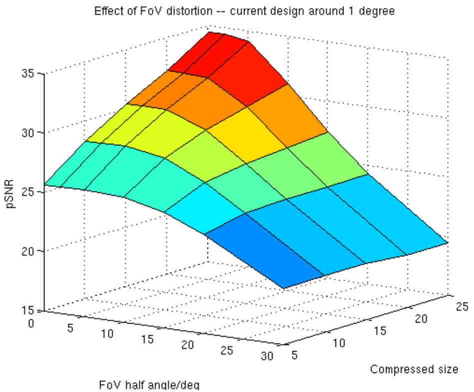
- CS requires data to be sparse in some basis.
- Natural images appear sparse using Haar wavelet basis.
- CS relies on sensing bases being incoherent with sparse bases.
- `Noiselets' are maximally incoherent with Haar.
- Noiselets are complex valued, with the components taking +1, 0, or -1 values, but can be transformed to real binary patterns for DMD use.

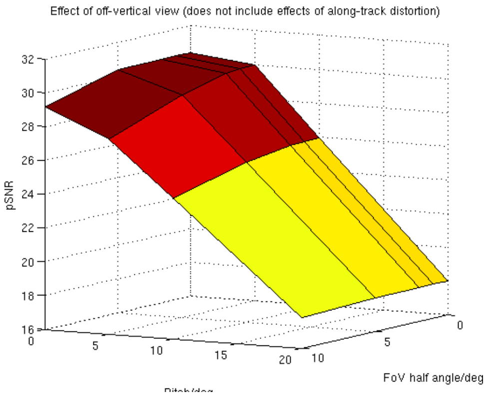
University of Strathclyde Science

Block Compressive Sensing (BCS) and Total Variation (TV) reconstruction Simulation Results with 40% Sampling

Method	SSIM (1 is lossless)
OMP	0.544
NESTA (uses TV)	0.886

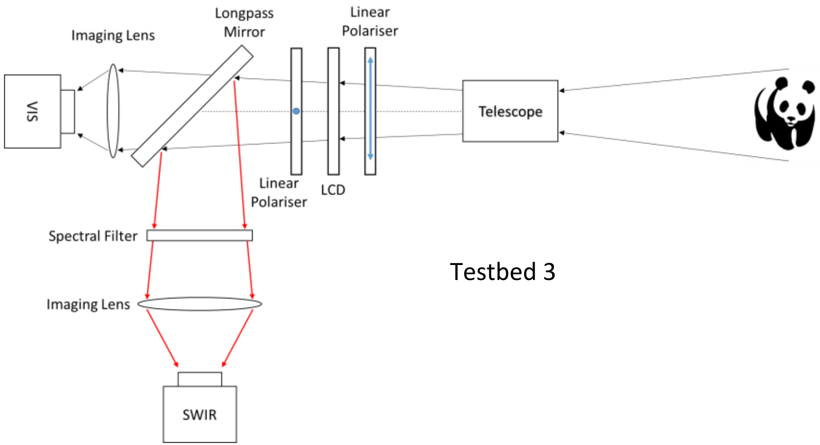






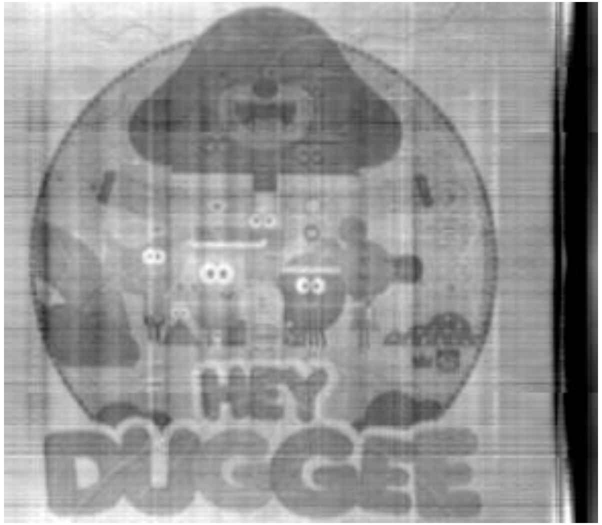
CS Experimental

Preliminary results using modified spatial modulator and mask geometry

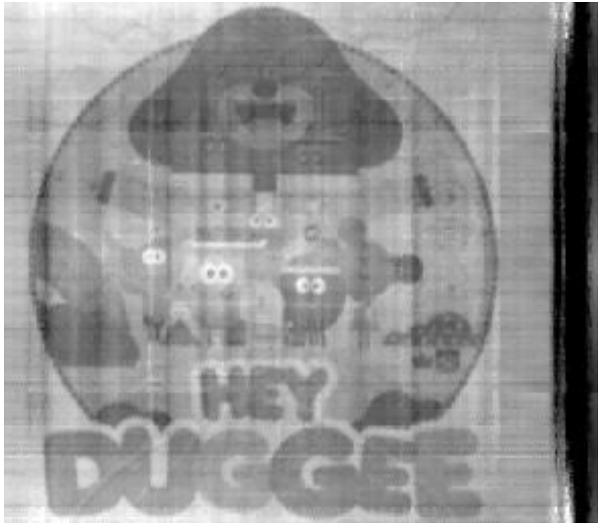


Testbed 3

256x256



100%



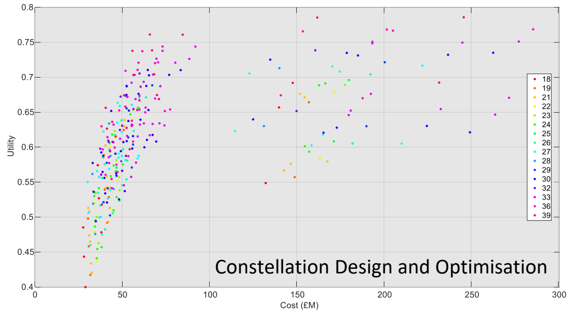
50%

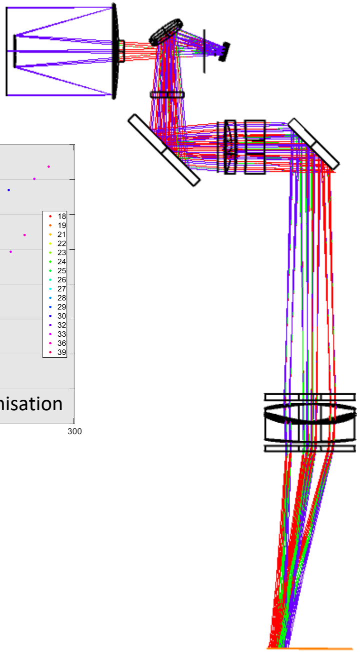
25%

Future Work

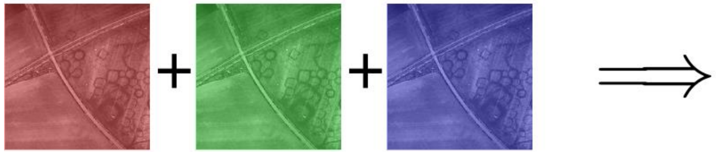
(COVID-19 Dependent)

- Solve 1D light integrator, reach etendue limits, optimised integrated optical design
- Theory
  - Improve CS patterns and reconstruction
  - Continue analysis of optics non-idealities and reconstruction
  - Multispectral CS
- Design adaptive pattern, algorithms
  - Scanning, detection, identification
  - Trade-off between compression, data quality
- Characterise multispectral performance of Prototype
- Novel optical architectures for CS MSI

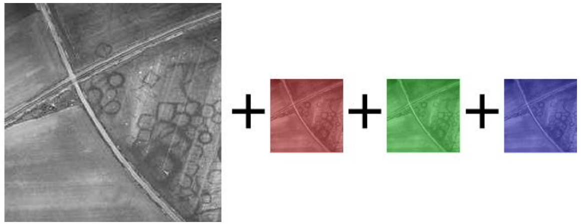




1D Optical Integrator
Initial Design

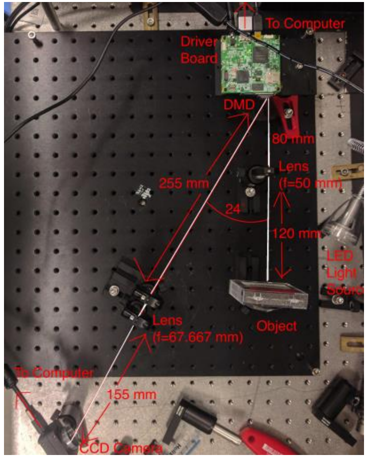


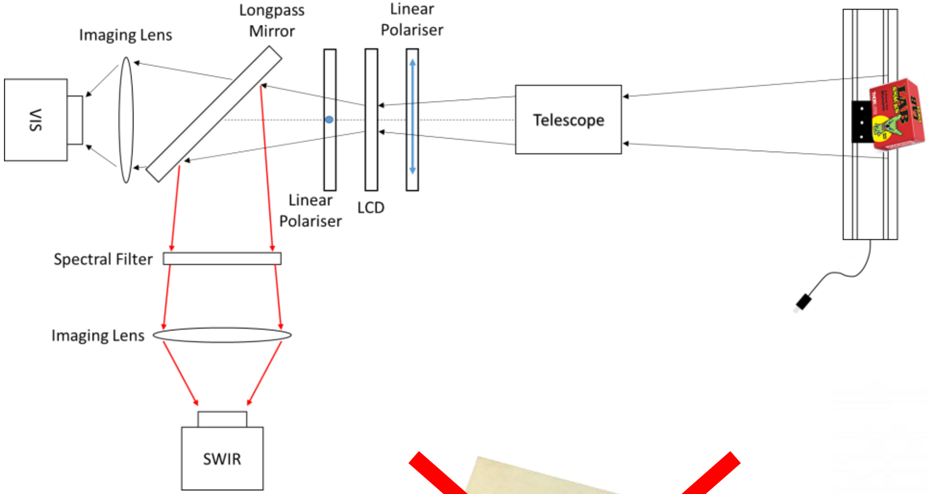
Exploit spectral correlation in CS sampling and reconstruction



Extra Slides

New experimental setup





- Better geometry
- Greater light loss
- Non-optimal SWIR performance