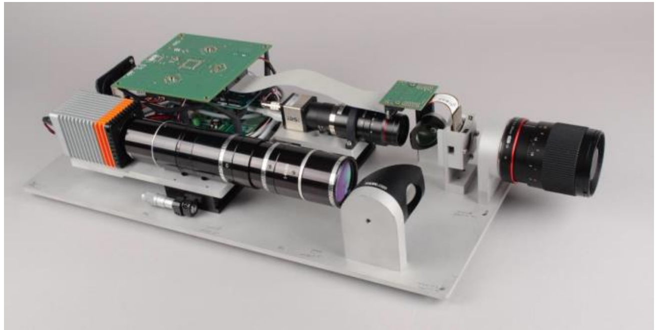


Compact Multi-Spectral Imager for Nanosatellites II

CEOI 11th Call

Stuart Bennett and Daniel Oi (PI)

CEOI Technology Showcase 24th June 2021

Agenda and team

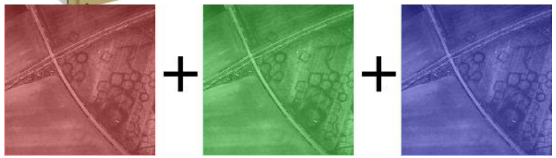
- Aims
- Single Pixel Imaging
- Pushframe Imaging
- Prototype
- Results
- Future Steps

- 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 (Centre for Signal and Image Processing)
  - **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 engineer
  - **Niall Slater:** Mechanical engineer

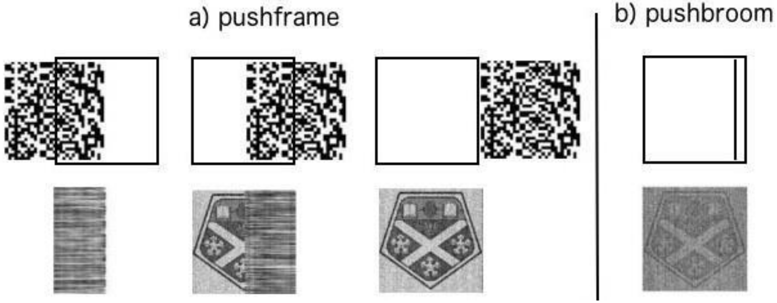
CMSIN aims

Implement and demonstrate a:

- compact – suitable for smallsat constellations

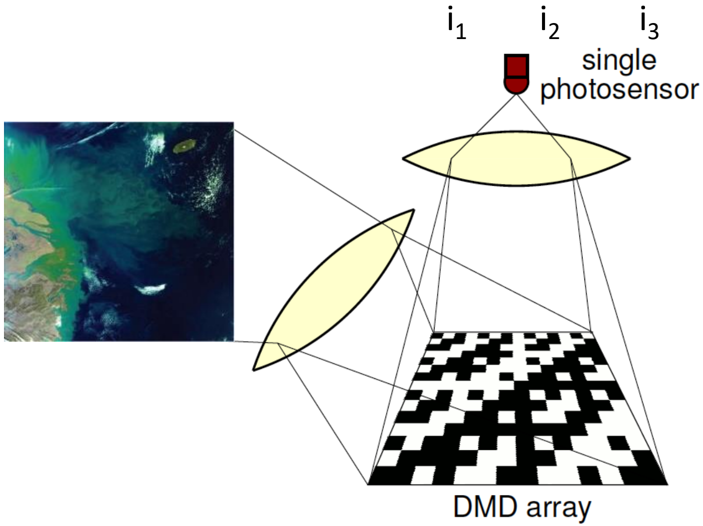


- co-registered multispectral – flexible and capable
- compressive sampling – optically-reduced bandwidth requirement
- pushframe imager – high SNR

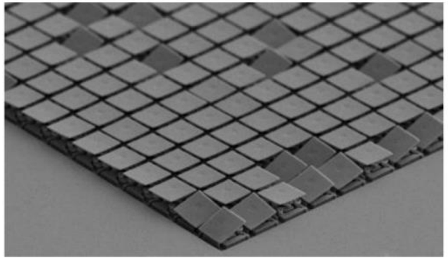


Single-Pixel Imaging (SPI)

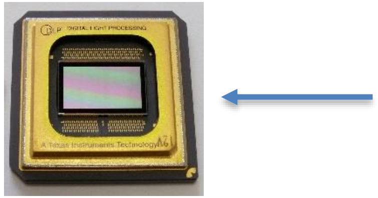
- Modulated spatial information captured by single pixel, *multiple patterns and exposures*
- Space-efficient, and simple electronics
- Imaging at wavelengths where 2D arrays expensive
- Can perform 100% sampling (Hadamard matrices etc.) or Compressive Sampling
- Potential for adaptive measurements

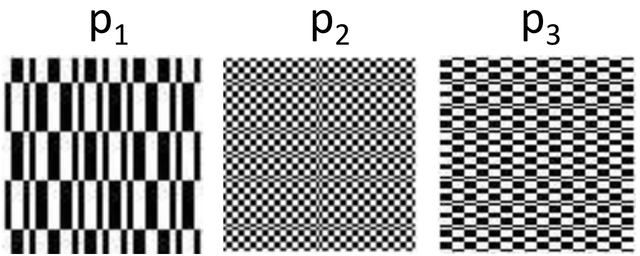


Spatial Light Modulator (SLM): an LCD or Digital Micromirror Device (DMD) for broadband performance



All bands automatically co-registered as sampled/reconstructed via same mask

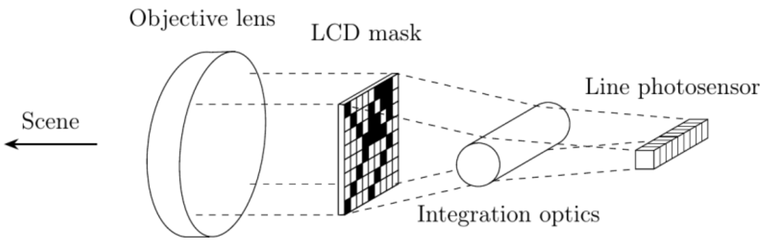


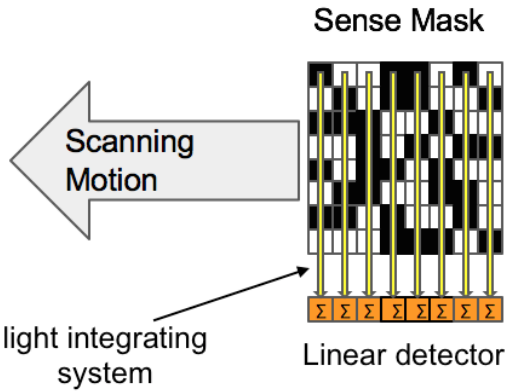


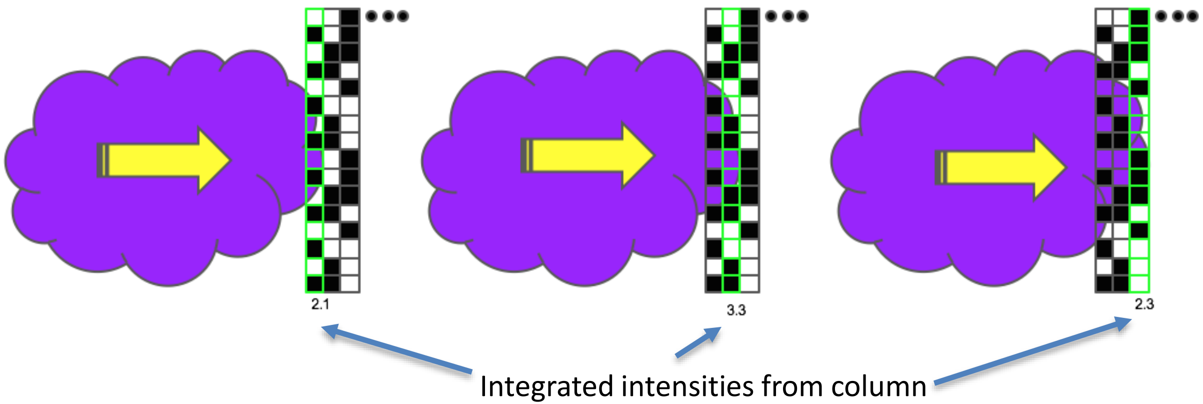
Pushframe Imaging

Compact multispectral pushframe camera for nanosatellites
Yoann Noblet et al.
DOI: 10.1364/AO.399227

- Parallelizes exposure to reduce capture time
  - Multiple adjacent 1D Single Pixel Imagers
  - Overcomes sampling time limitation of conventional SPI
- Similar to pushbroom operation
  - Using a fixed pattern, along-track motion applies different mask columns to each scene-strip automatically
- Advantages over pushbroom
  - SNR improvement, particularly when read-noise limited
  - Compressive Sampling possible
  - ‘Optical processing’ enables adaptive operation



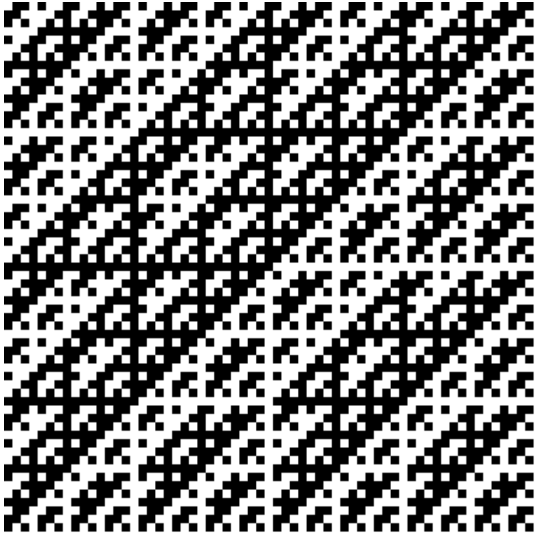




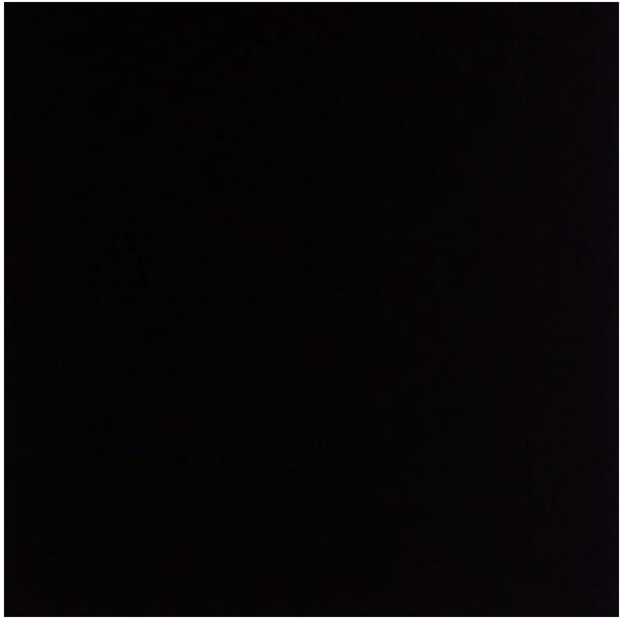
Pushframe in operation

Scene

Mask

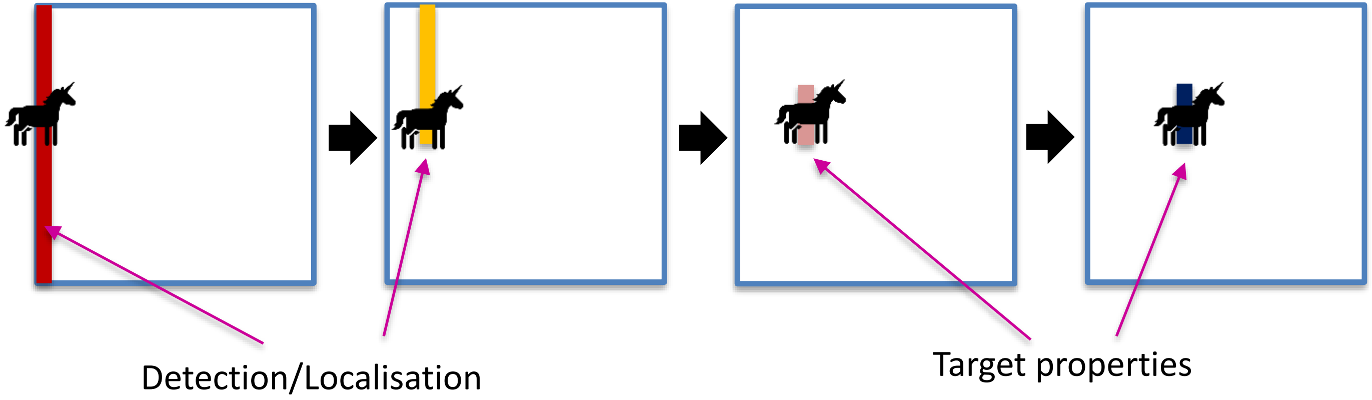


Capture



Adaptive Sampling

Reduced data acquisition, low power monitoring

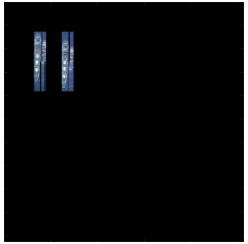


Sense patterns adaptively chosen based on preceding “signatures”

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

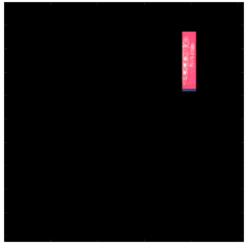
Simulated pushframe imaging with adaptive sense patterns

(a) Monochrome source image



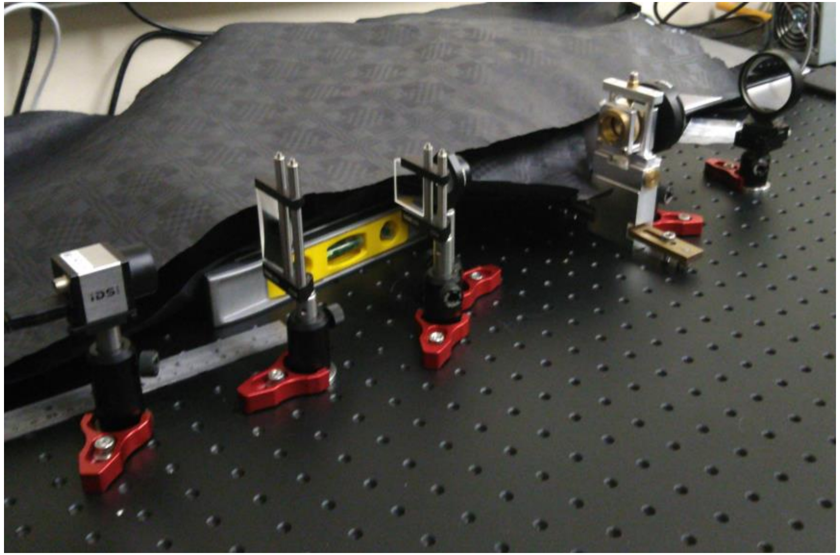
(b) Acquired image, 2.3% of source

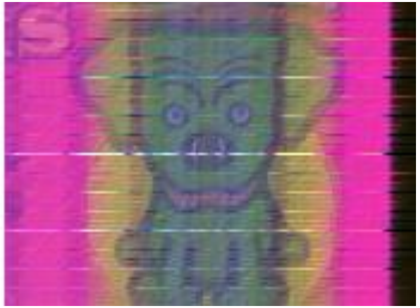
(c) Multi-spectral source image



(d) Acquired image, 1.5% of source

Pushframe demonstration

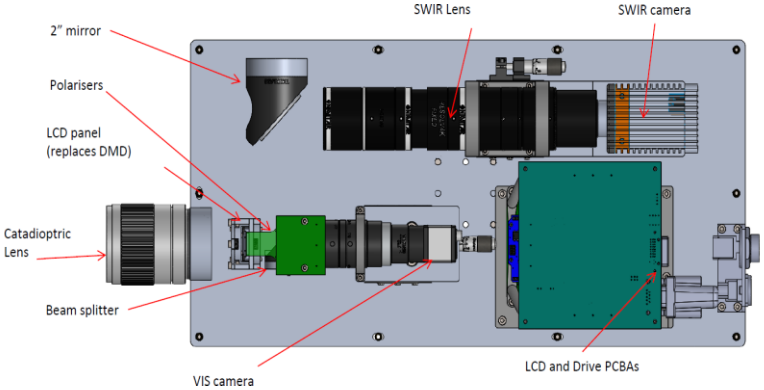


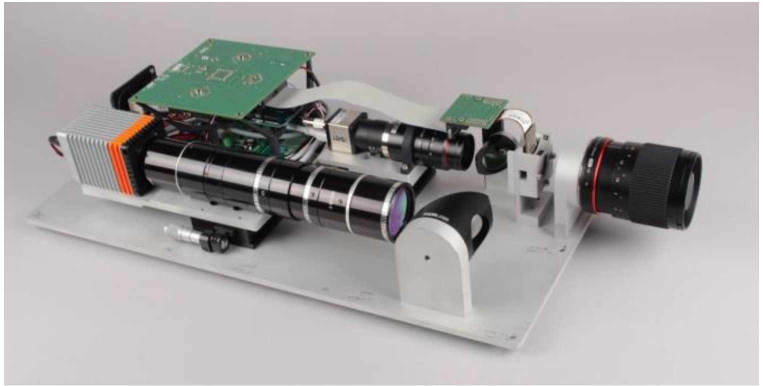


- First experimental demonstration of an optical pushframe camera
- COTS components
  - limited resolution (64x64)
  - limited optical performance
  - low 1D compression (2:1)
- Encouraging results
- Principle proved

Prototype

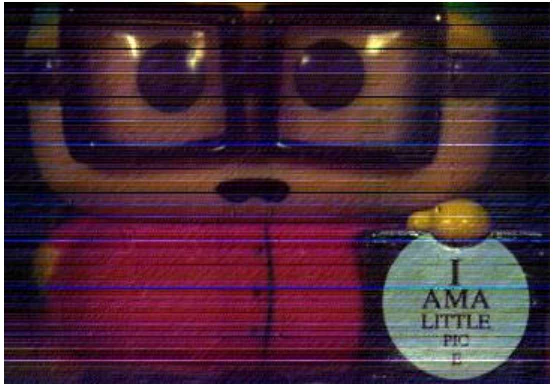
- Built around off-the-shelf components
  - simulated 1D optical integration pragmatic and allows analysis and diagnostics
- Fits in a 6U envelope
- Co-registered multi-spectral imaging
- LCD was chosen for:
  - compactness
  - good optical performance
- Interchangeable front telescope
- ‘Field deployable’





Laboratory results

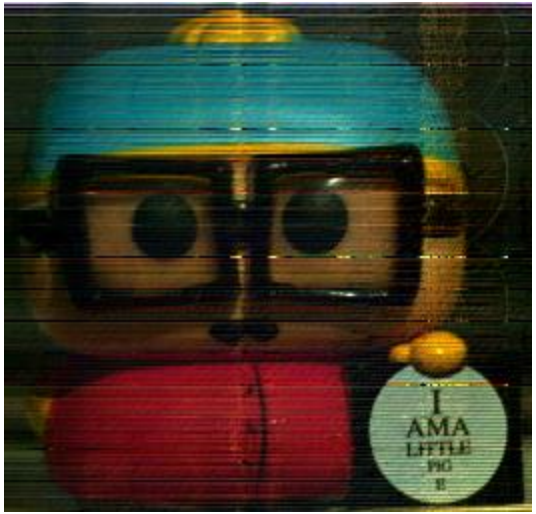
University of Strathclyde Science

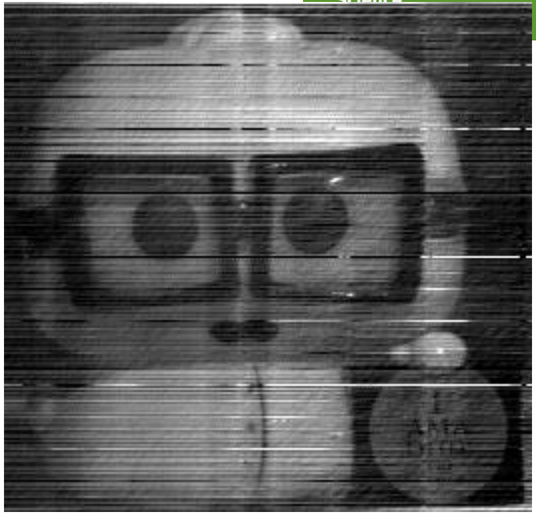


- First demonstration of co-registered multi-spectral imaging
- Good fidelity in both the visible and SWIR
- Maximum resolution of 256x256 pixels

Field trials

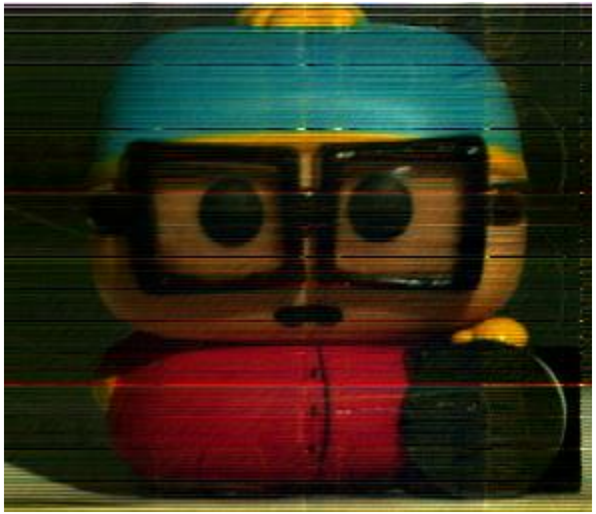
University of Strathclyde Science

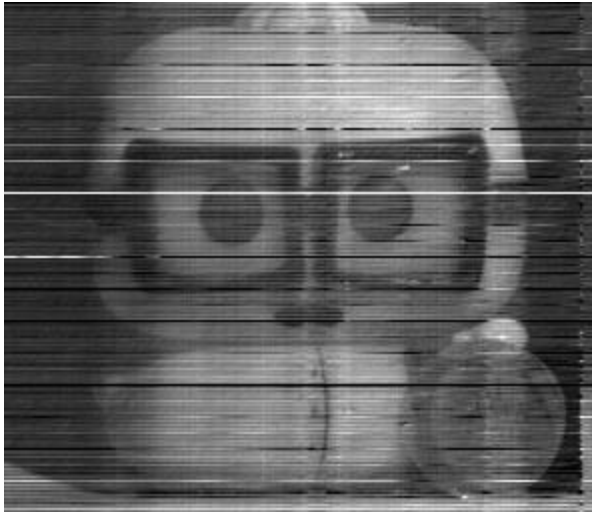




- First field results, under uncontrolled conditions, of a pushframe camera
- Good fidelity, similar to that achieved in the laboratory

NIR Si capability demonstration



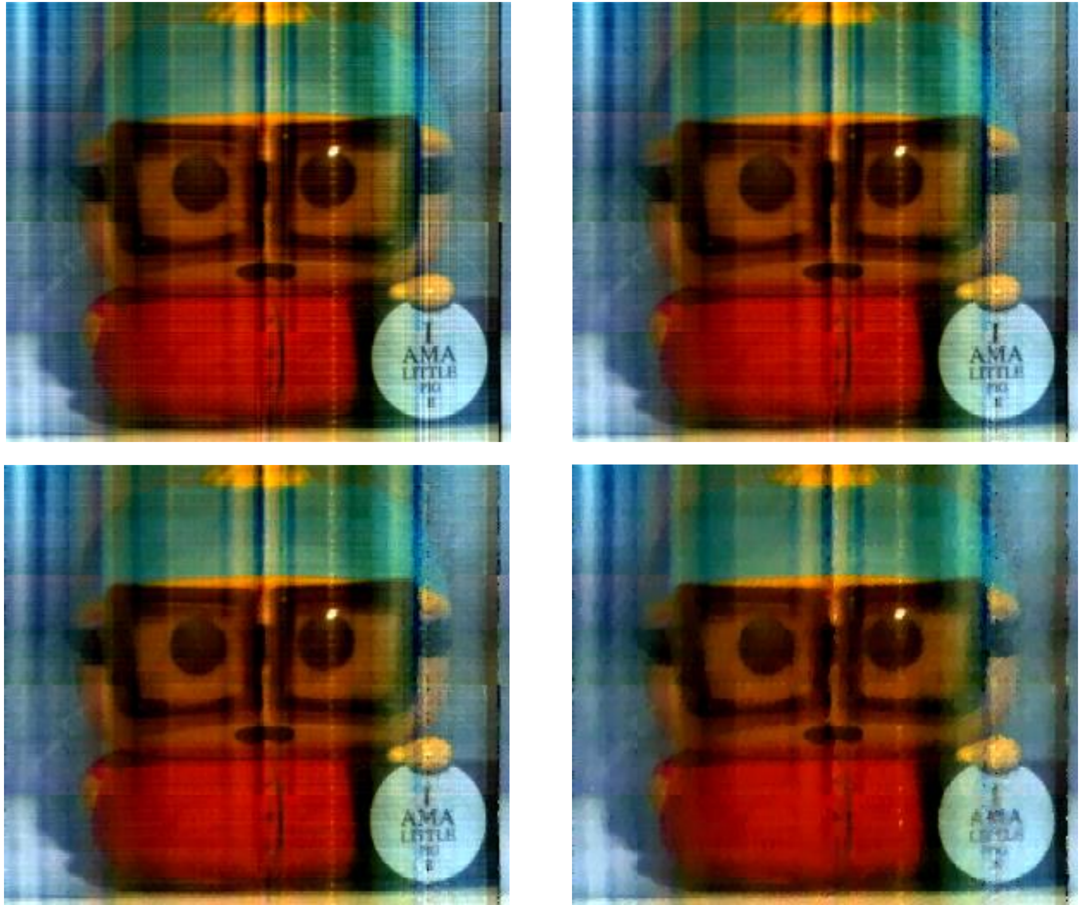


- Demonstration of the multispectral capabilities of the device
- The (outline of the) text disc is apparent in the SWIR whereas it is "hidden" in the visible

Compressive sampling

Compressive Sampling Using a Pushframe Camera
Stuart Bennett et al.
https://arxiv.org/abs/2104.13085

University of Strathclyde Science



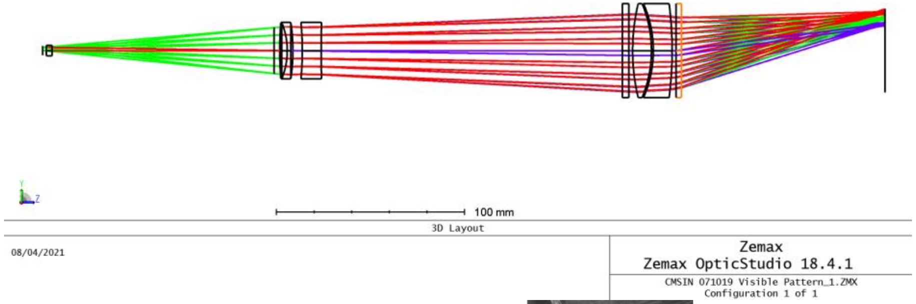
- Demonstration of the prototype's flexibility
- Reduces data rate for storage and transmission
- Uses bespoke 2D 'columnar block' adaptation of binary 'noiselet' basis to achieve SPI-like performance
- 100%, 60%, 40% and 20% sampling rate
- Good fidelity at 40%
- Affecting image quality significantly at 20%
- CR selectable without changing mask (useful for pansharpening)

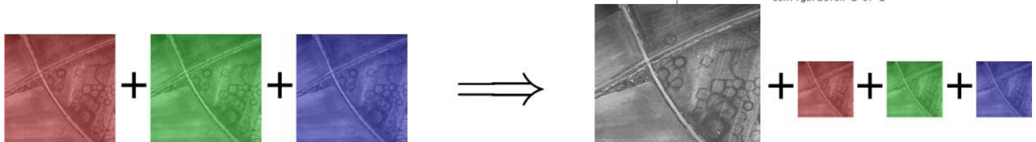
Future Steps

University of Strathclyde Science

Technical

- Pushframe Algorithms
  - Columnar Compressive Sensing Theory
  - Multispectral Sampling and Reconstruction
  - Joint spatio-(hyper)spectral compressive sampling theory
  - Adaptive sampling development
  - Pattern development
  - Compressive detection and characterisation
- 1-D Optical Integration
  - Non-imaging optical system development
  - Multimode waveguide integrators
  - Free-form optics design
  - Diffractive optics design
- Spatial light modulator development
  - Optimisation of imaging optics onto SLM
  - Optimisation of SLM collection optics
  - MEMS SLM design, new concepts for pattern generation
- Sensor Development
  - On-chip 1-D integration
  - Low-power adaptive pushframe detection and characterisation
- Payloads and Missions
  - Satellite payload design
  - Mission design





Multispectral Reconstruction

Markets/Users/Application

- Novel applications of pushframe imaging
  - Non-EO applications, e.g. autonomous vehicles
  - Monitoring and detection mission development
- Markets
  - Ongoing research
- Users
  - New and continuing engagement