Project Report LSP-251

CRISP Flight Campaign: FY18 Optical Systems Technology Line-Supported Program

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17 January 2019

Lincoln Laboratory

MASSACHUSETTS INSTITUTE OF TECHNOLOGY Lexington, Massachusetts



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Lexington

Massachusetts

EXECUTIVE SUMMARY

The CRISP multiplexing architecture enables high performance and low SWaP hyperspectral imaging systems. A flight ruggedized CRISP spectrometer was designed and built for a flight demonstration on Lincoln Laboratory's Cessna aircraft. Flight tests to collect emissivity spectra of sand and ocean water over the Plum Island and Cape Cod regions have demonstrated that the CRISP concept is robust under real-world conditions.

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1. INTRODUCTION

Hyperspectral Cube Spectrum of each pixel Wavelength, λ · Hyperspectral imagers provide detailed spectra of each spatial pixel - 'Hyperspectral cube' has 2 spatial (x,y) dimensions and 1 spectral (λ) dimension

1.1 WHAT IS HYPERSPECTRAL IMAGING (HSI)?

1.2 WHY HYPERSPECTRAL IMAGING?



Chemical/biological agents; **IED** manufacture

Camouflage



Urban emissions¹

- Many materials related to dangerous activity have unique signatures in the infrared •
- · HSI identifies signatures and pinpoints dangerous activities

1.3 IMAGING SPECTROMETER CHALLENGES

<u>Challenge</u>: Imaging spectrometers expensive, hard to miniaturize

- Typically (infrared) require cryogenically cooled focal planes to achieve required performance
 - Liquid nitrogen-cooled HgCdTe arrays
 - Expensive to launch; limited lifetime



- Goal: Global, persistent coverage

· E.g., Small satellite constellation



1.4 CONVENTIONAL 3-COLOR RGB IMAGING



1.5 PASSIVE IMAGING SPECTROMETERS



1.6 SPECTRAL IMAGING SYSTEMS



2. MULTIPLEXING, COMPUTATIONAL IMAGING, AND CRISP... DOING MORE WITH LESS

2.1 MICROBOLOMETERS AND MULTIPLEXING



2.2 CRISP SPECTRAL DECODING



CRISP more sensitive than dispersive + FTIR, for both shot-noise and detector-noise limited measurements

· CRISP advantage maximized with noisy detectors

2.3 HYPERSPECTRAL IMAGER OPERATION



2.4 COMPARISON OF HSI SYSTEMS

	Pushbroom	FTIR	CRISP	
	12 miles	College College		A Ω Etendue -Optical throughput (same for all) -Dwell time (differ)
Spectral formation for single pixel	GSD At	M = 2 NA	$M \ge N_{\lambda}$ $x = \phi^{-1} y$	
Dwell time	∆t	M At	M At	
Throughput	-1-	1/2 (beamsplitter)	1/2 (mask)	
Photon- limited SNR	SNR _{Pushbroom} = 1	$\frac{SNR_{FTIR}}{SNR_{Pushbroom}} = \frac{1}{2}$ [1]	$\frac{SNR_{CRISP}}{SNR_{Pushbrown}} = \sqrt{\frac{M}{2N_{\lambda}}}$ [2]	1 M
Detector- limited SNR	$\frac{SNR_{Pushbroom}}{SNR_{Pushbroom}} = 1$	$\frac{SNR_{FTIR}}{SNR_{puxhbroom}} = \frac{1}{4} \sqrt{\frac{M}{2}}$ [1]	$\frac{SNR_{CRISP}}{SNR_{Pushbrown}} = \frac{\sqrt{M}}{2}$ [2]	M = # of measurements SNR = μ/σ

CRISP multiplex advantage improves performance in both photon-limited and detector-limited situations - Improves with number of measurements M (FPA size)

3. CRISP PROOF-OF-CONCEPT

3.1 CRISP PROOF-OF-CONCEPT TESTBED



3.2 CRISP HYPERSPECTRAL IMAGERY





3.3 CRISP APPLICATION: TRACE PLUME DETECTION



3.4 CRISP SENSITIVITY ADVANTAGE



4. CRISP FLIGHT TESTS

4.1 CRISP FLIGHT TEST PROGRAM FY18 OST LINE



Goal: Demonstrate viability of CRISP concept from moving platform
 – Measure performance in presence of motion and jitter

4.2 CRISP FLIGHT COLLECTIONS



4.3 CRISP SPECTRA: PLUM ISLAND COASTLINE



4.4 CRISP HYPERSPECTRAL IMAGERY



5. ACKNOWLEDGEMENTS

- · CRISP team
 - Ryan Sullenberger, John Lessard, Yaron Rachlin, Zach Palmer, Sumanth Kaushik (Gp 91)
 - Adam Milstein (Gp 97)
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- Funding
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Publications

- Computational reconfigurable imaging spectrometer", R. M. Sullenberger, A. B. Milstein, Y. Rachlin, S. Kaushik, and C. M. Wynn, *Opt. Expr.* <u>25</u>, 31960 (2017).
 - Invention disclosure: "Computational reconfigurable imaging spectrometer (CRISP)", A. Milstein, Y. Rachlin, C. Wynn, R. Sullenberger, S. Kaushik; Filed 2017.

REFERENCES

Sullenberger, Ryan M, Adam B Milstein, Yaron Rachlin, and Kaushik Sumanth, "Computational reconfigurable imaging spectrometer," *Opt. Expr.* 25 (31960), 2017.