Fiber based - VIS and SWIR Snapshot Spectrometers

NASA Instrument Incubator Program

PI / Presenter:
Tomasz S. Tkaczyk, Rice University

Team:
Rice University: David Alexander, Christopher Flynn, Jiawei Lu, Ye Wang, Razvan I Stoian, Desheng Zheng
NCAR: Ethan Gutmann
CU: Bruce Kindel

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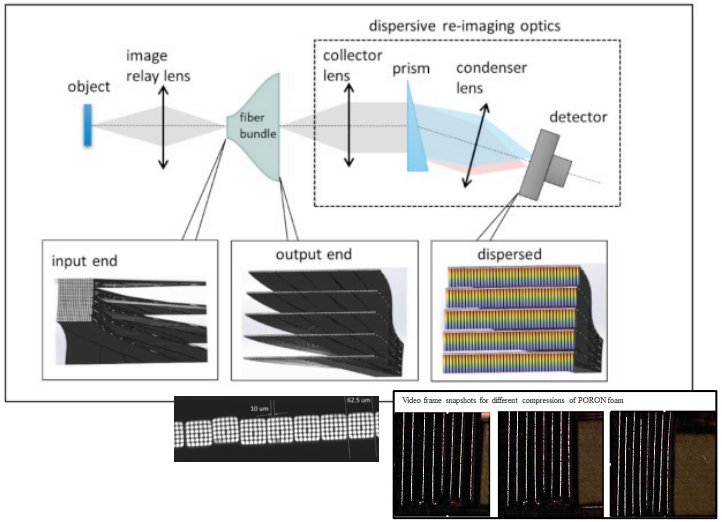
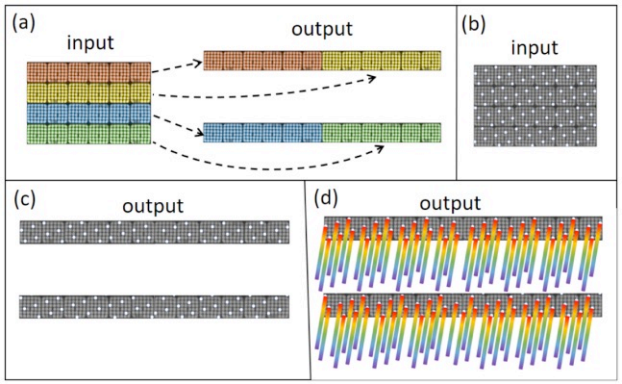
Principle of TuLIPSS Technology





- Custom fiber light-guide reformats image to create void spaces to allow spectral cube acquisition in a single – snapshot (cube is acquired instantaneously with no-scanning)

Y. Wang, M. E. Pawlowski, S. Cheng, J. G. Dwight, R. I. Stoian, J. Lu, D. Alexander, T. S. Tkaczyk "Light-guide snapshot imaging spectrometer for remote sensing applications," *Opt. Express*, 27, 11, 15701-15725 (2019). DOI: https://doi.org/10.1364/OE.27.015701.

Advantages of Snapshot 3D+ Detection

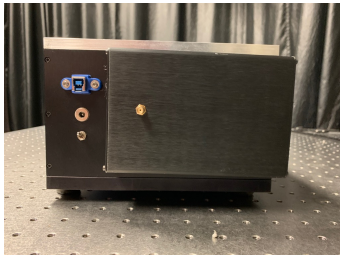
- Monitoring of fast processes
  - Range: FPA speed to end-user-specified timeframes
- Immune to vibrations/movements
- 3D capability for snapshots taken at different inclinations/zenith
  - Tomography, topography
- Improvement of signal quality
  - Via scene overlap (UAV/satellite speed-dependent)
- Glint compensation
  - Via tilting capability
- Orbital scanning for imaging scenes adjacent to “along-track” direction
- Reverse gimbaling for prolonged exposure/integration time/number of images to improve signal quality and resolution for area of interest
- Predicting scene change for setting tuning parameters (for example augmented integration for HDR)

VIS and SWIR Fiber Based Imaging Spectrometers

GEN1 - Field VIS system (470-700nm)

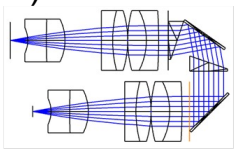
- Length: 600 mm
- Width: 220 mm
- Height: 133 mm
- Spatial image points – approx. 63,000 (250x250)
- Spectral Sampling: 35

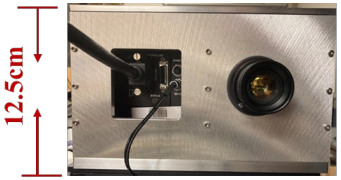
Mass = 15.8kg



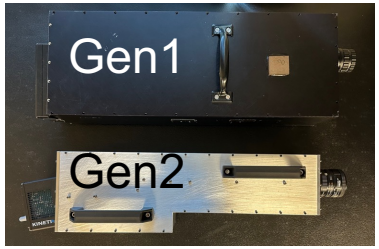
GEN1 - Field SWIR system (1050-1300nm or 1100nm-1600nm)

- Length: 420 mm
- Width: 210 mm
- Height: 125 mm
- Spatial image points – upto. aprox. 17,500 (130x130)
- Spectral Sampling: 20-40 (depends on disperser)



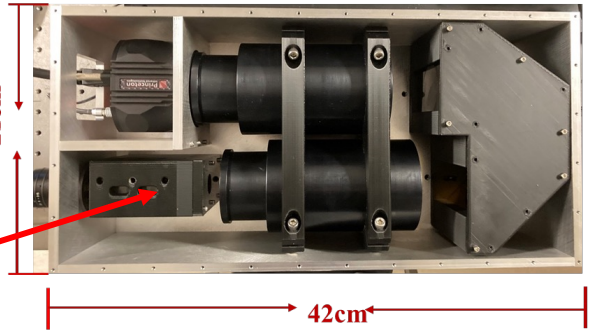


GEN2 - Field VIS system (525-750nm or 650-1000nm)



- Length: 540 mm
- Width: 170 mm
- Height: 120 mm
- Spatial image points – approx. 125,000 (350x350)
- Spectral Sampling: 41-43

Custom Bundle



Mass = 18.0 kg

Mass = 13.6 kg

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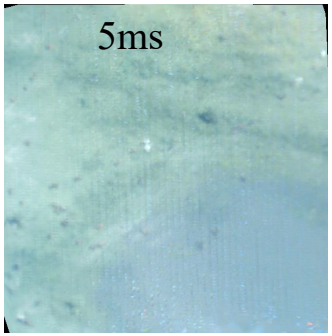
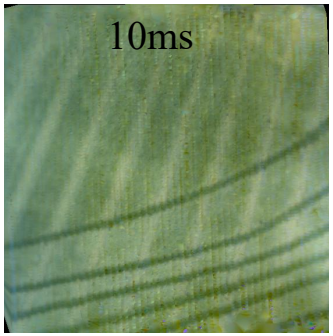
VIS ENGINEERING FLIGHTS

Flight 3: Review of composite videos taken at different integration times / elevations

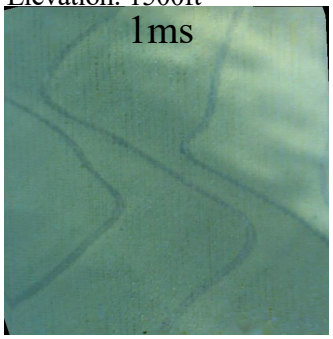
- First Engineering flight of 2021 achieved video rate image reconstructions at a variety of altitudes and exposures times.
- Time average flatfield over water taken from elevation 2000 ft, 10ms

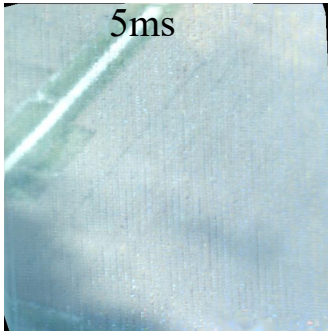
Elevation: 1000ft

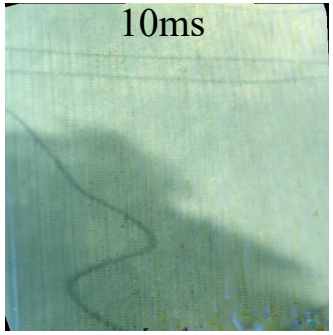




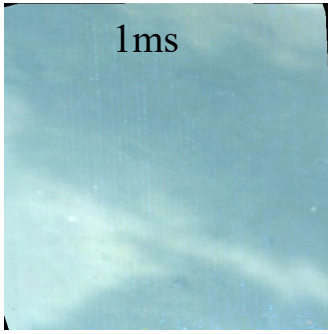
Elevation: 1500ft

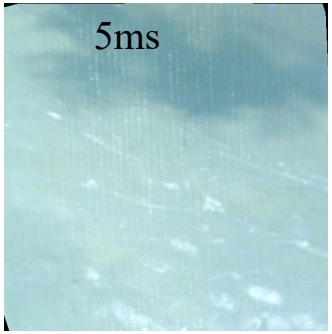


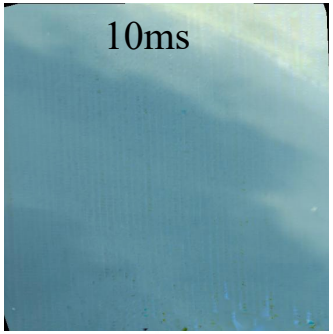




Elevation: 2000ft



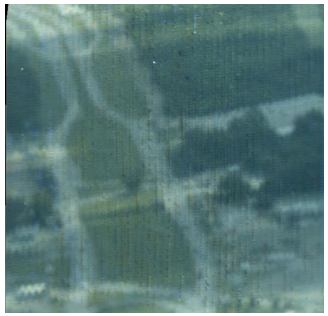




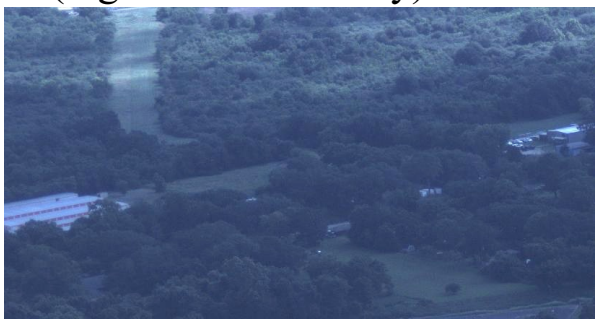
Flight 4: Alvin

- 1000ft over city of Alvin , at approx. 50 knots

TuLIPSS Video (10ms)



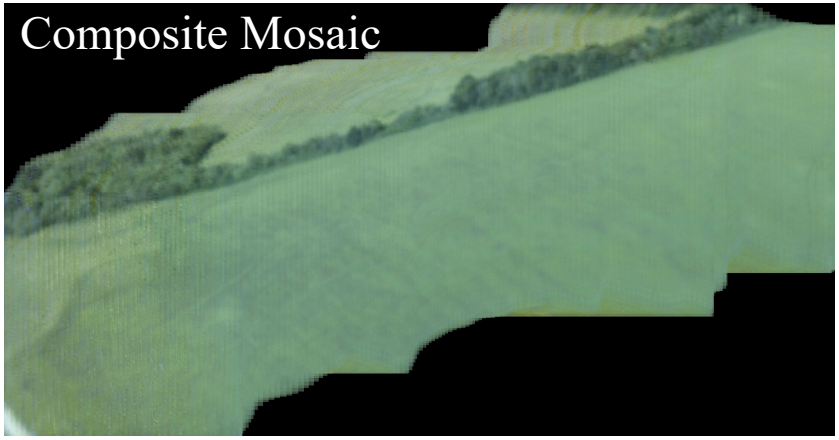
Fl3 Reference Video (high blue sensitivity)



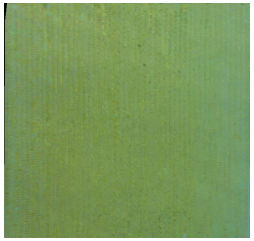
Mosaic (840 Images)

Flight 4 Field Data

Mosaic (180 images) and Composite Mosaic



TuLIPSS Composite Video



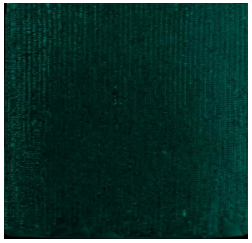
Reference Video

Reference image

Selected Spectral Channel Videos

467nm

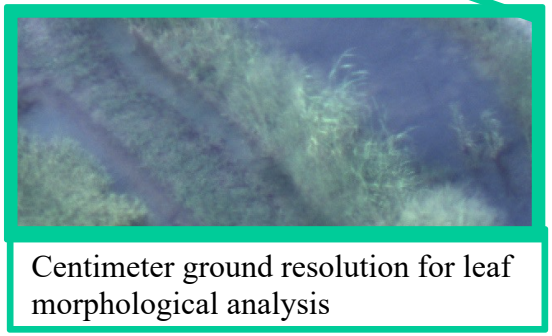
494nm



551nm

588nm

665nm



Centimeter ground resolution for leaf morphological analysis

TuLIPSS spectral capabilities and reference camera ground resolution enable multiple modes of analysis of plant stress toward crop production efficiency

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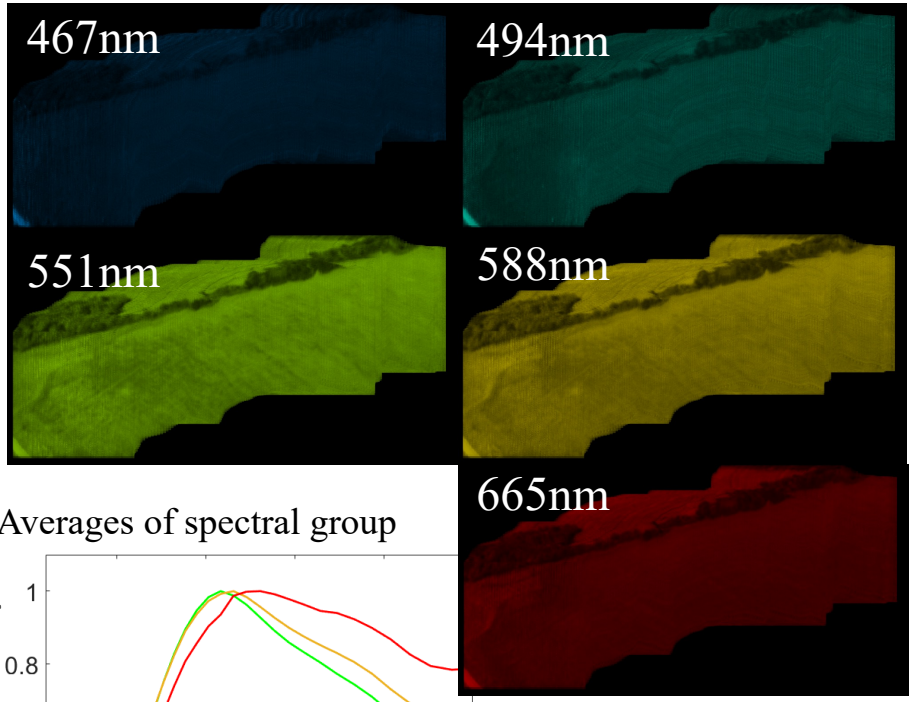
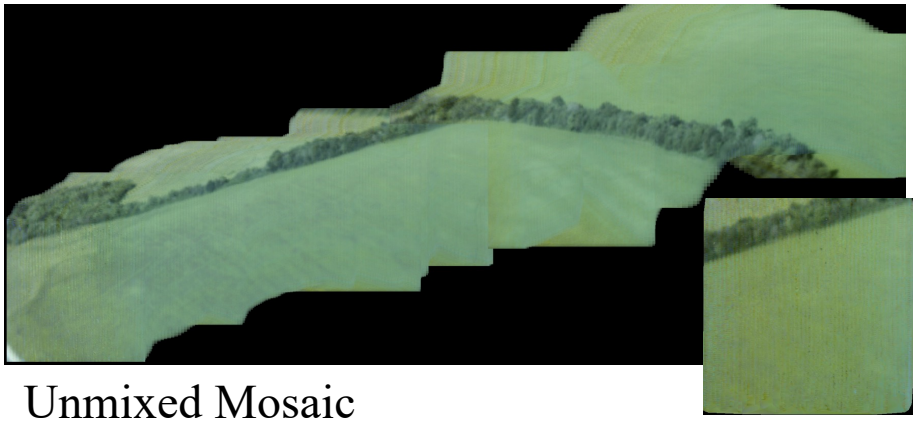
Field Spectral Unmixing

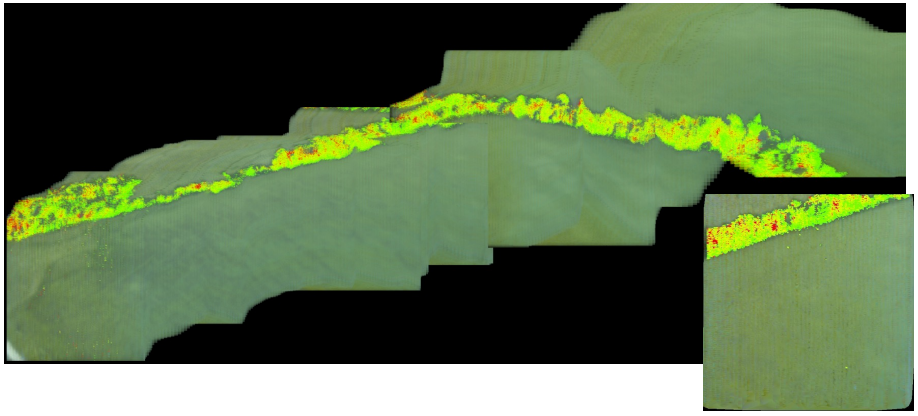
Mosaics of spectral wavelengths



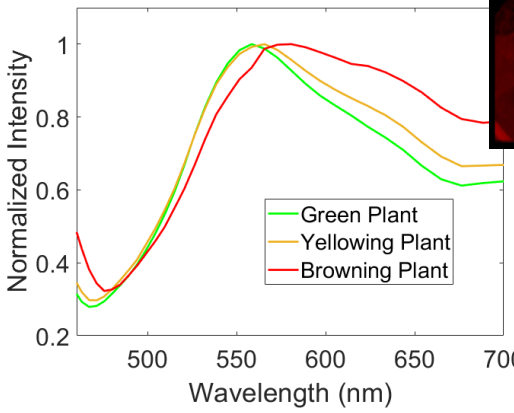
Composite Mosaic



Unmixed Mosaic



Averages of spectral group



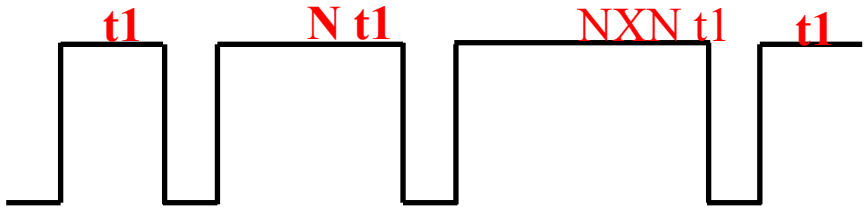
Separation of tree foliage by 550nm chlorophyll peak value to 650 absorption dip allows initial assessment of plant stress

AUGMENTED INTEGRATION FOR HDR DATA CUBES

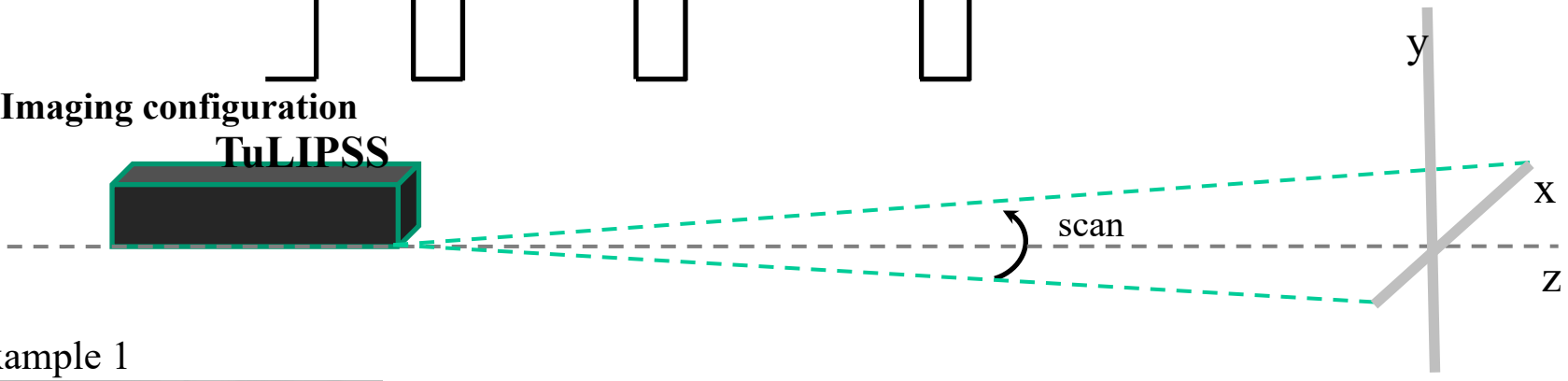
Augmented Integration Approach

1. Multiple exposure Augmented Dynamic range adjustable imaging

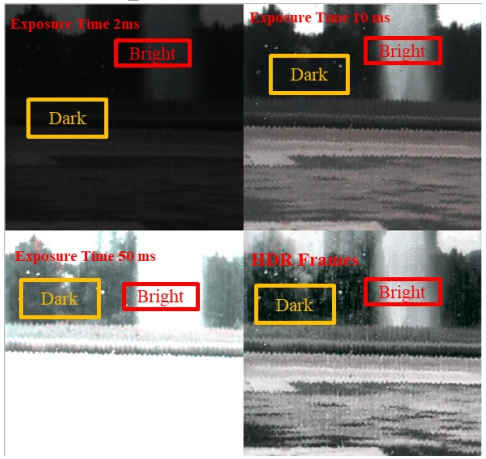
1.1 Strategy -- exposure time sequencing (t1, 2t1,4t1)



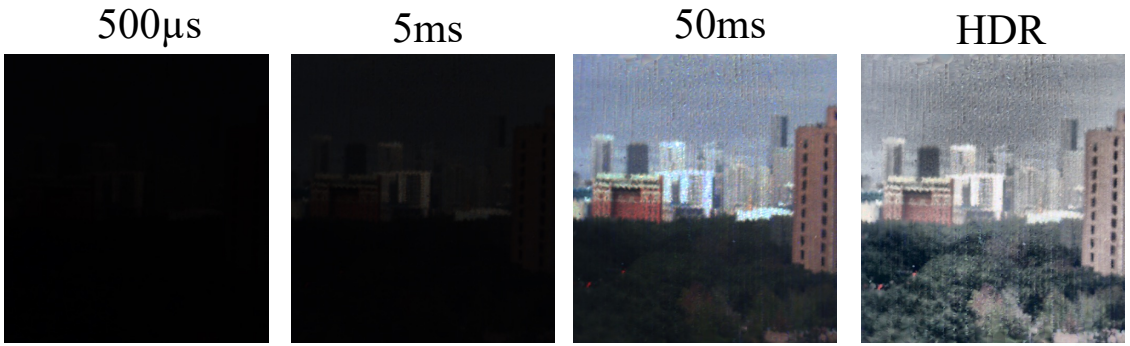
2. Imaging configuration



Example 1



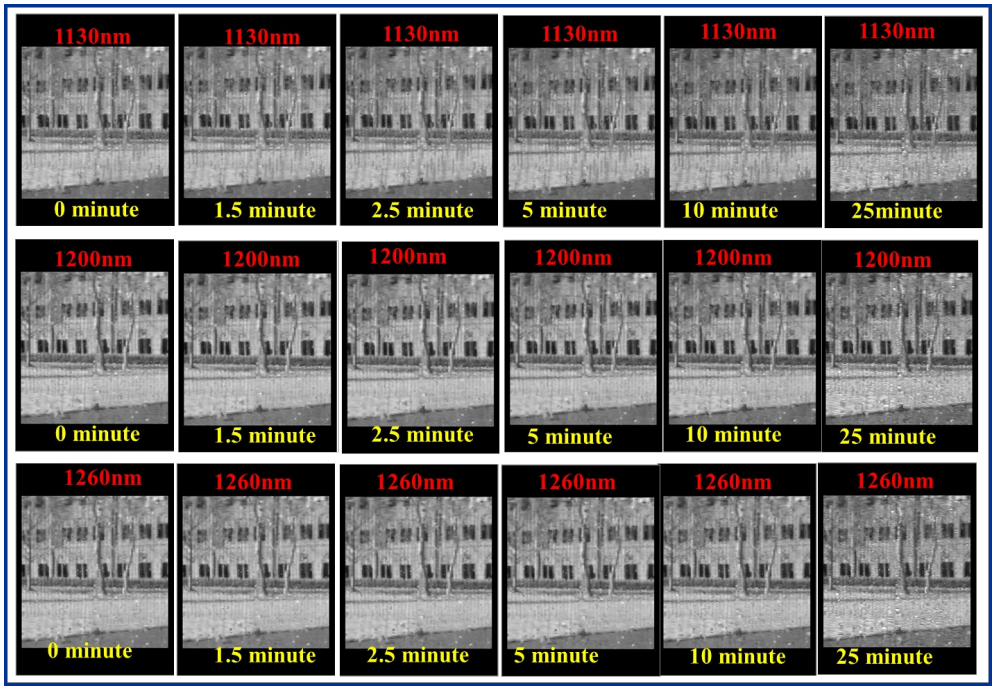
Example 2



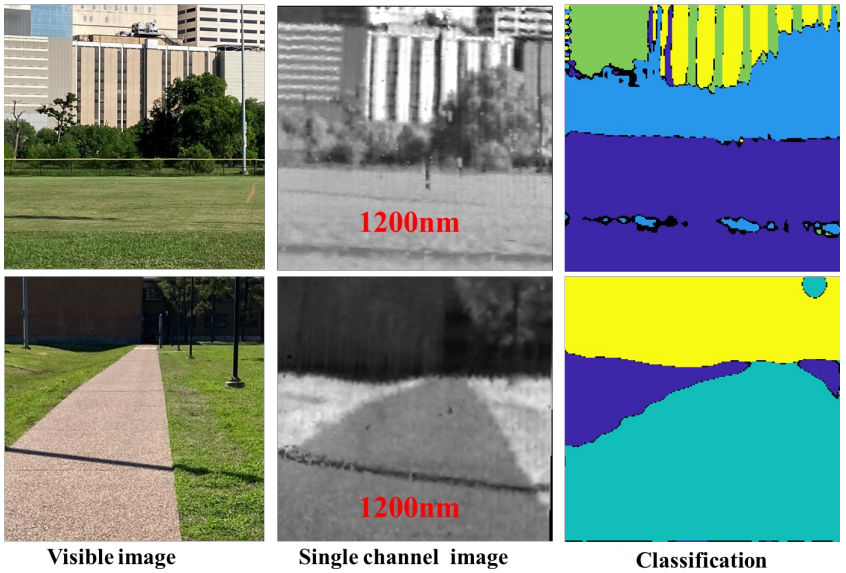
DIRECT WATER VAPOR DETECTION

Typical SWIR Data Stack / Classification

Selected Time Points / Spectral Channels



(3d-convolutional neutral networks)



Visible image

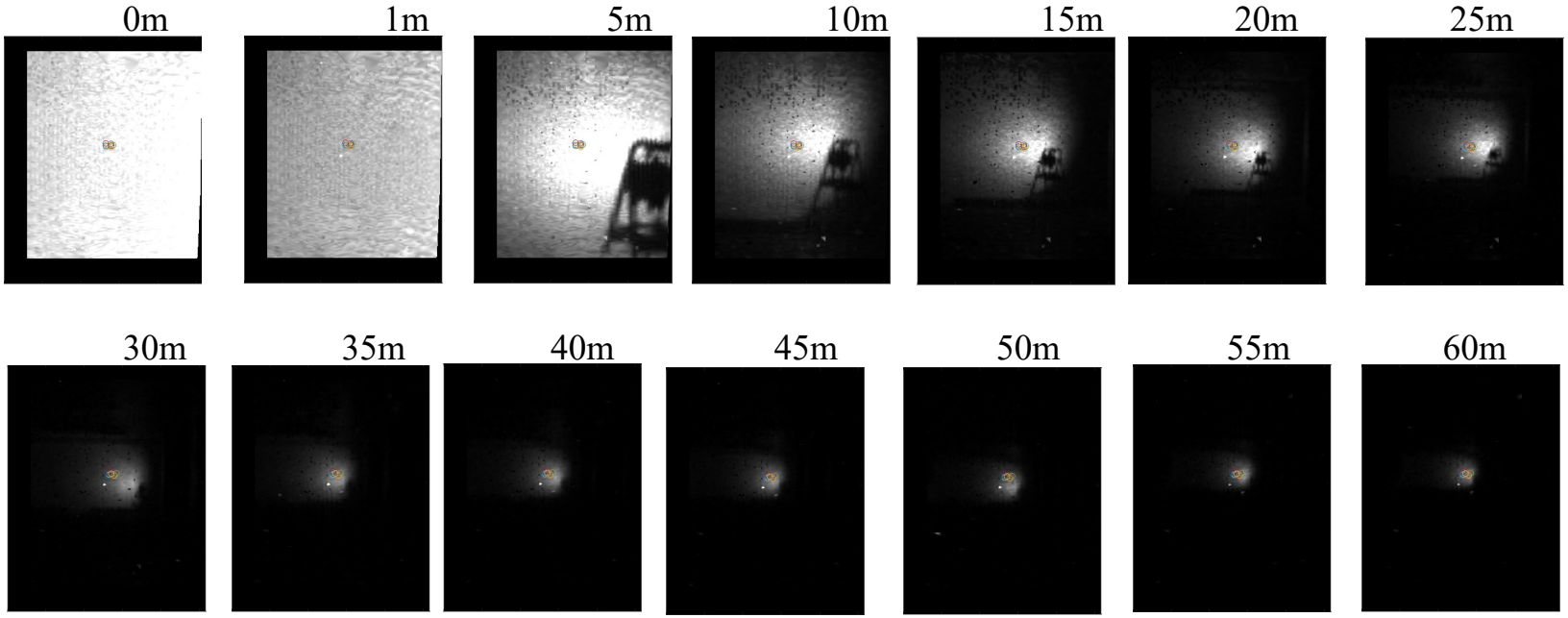
Single channel image

Classification

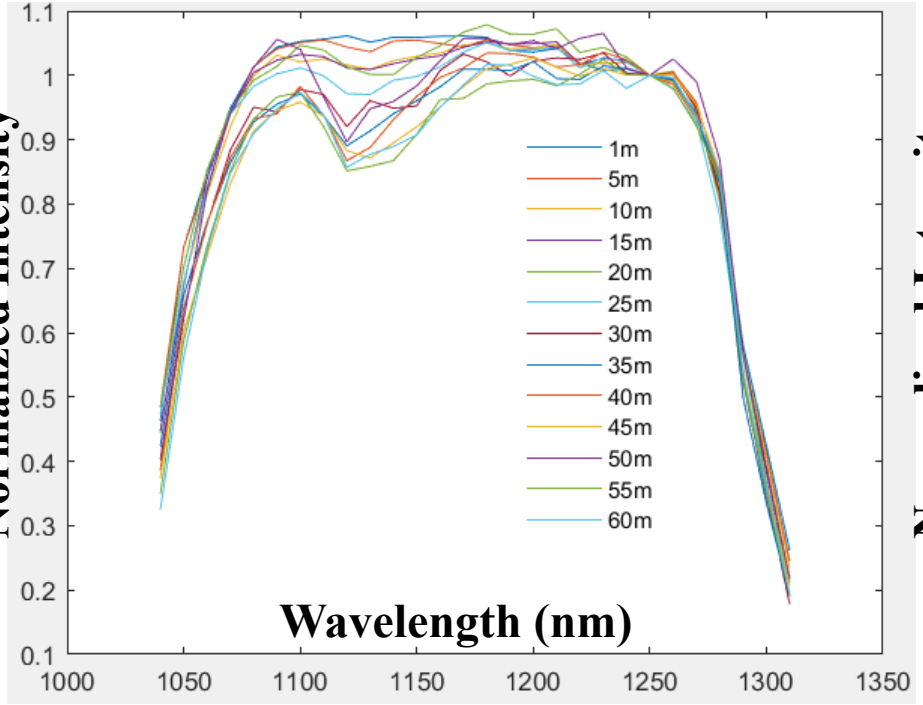
Vapor absorption distance dependence (white wall, garage B3, 06-08-2023)

Temperature 28.2, relative humidity 50.2%, vapor pressure 3653.4 pa

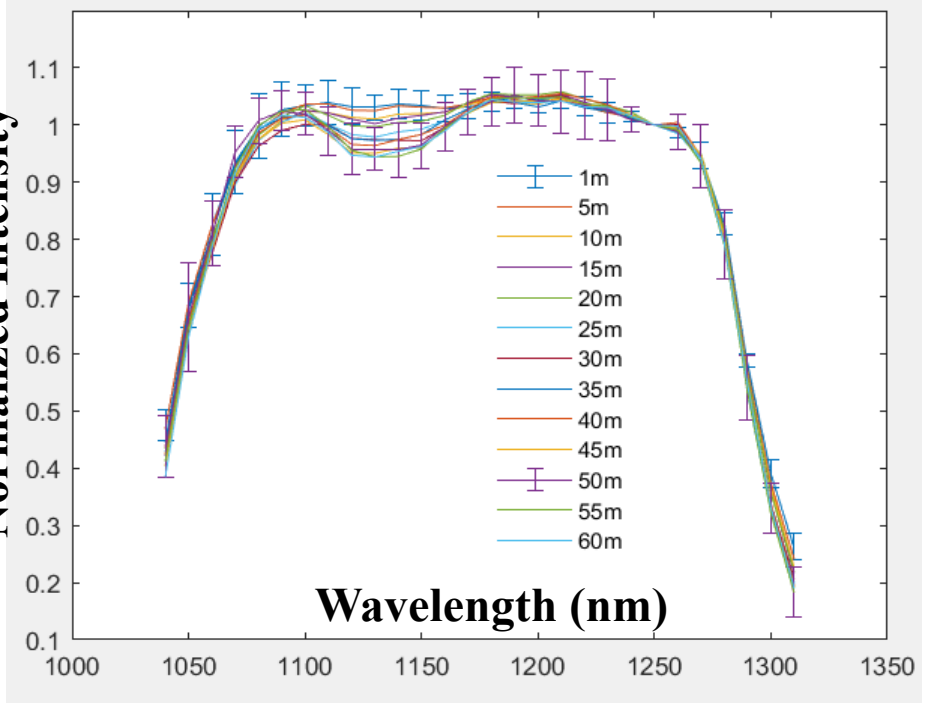
Use the same fiber cores to testing the vapor absorption



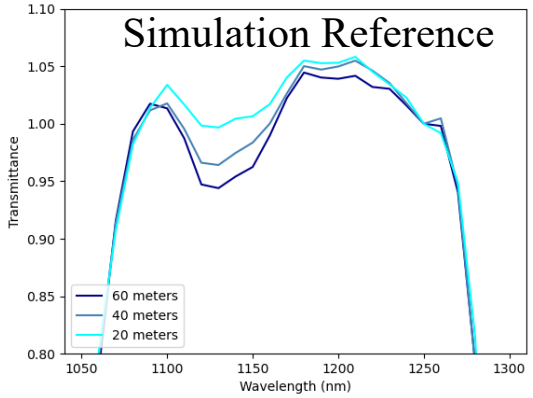
Reflection spectrum from Single fiber core



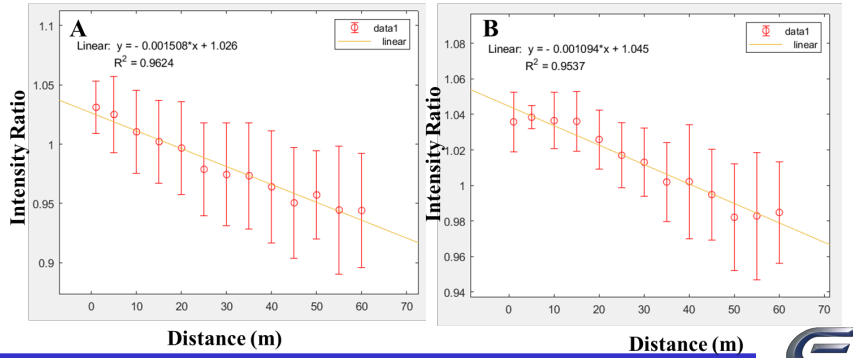
Averaged Reflection spectrum from 10 cores



MODTRAN Simulation Reference



A): distance dependence of Intensity ratio (I1130/I1240)
B): distance dependence of Intensity ratio { sum (I1100nm:I1180nm)/[4X(I1070nm+I1240nm)]}



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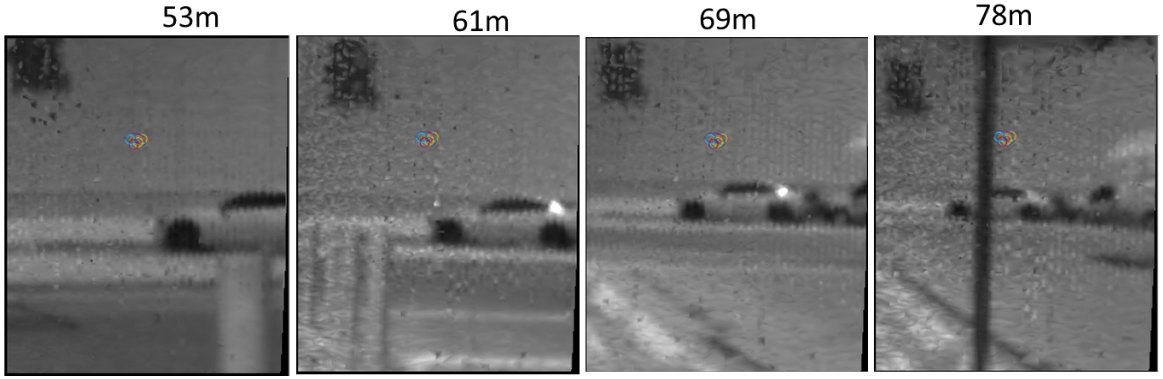

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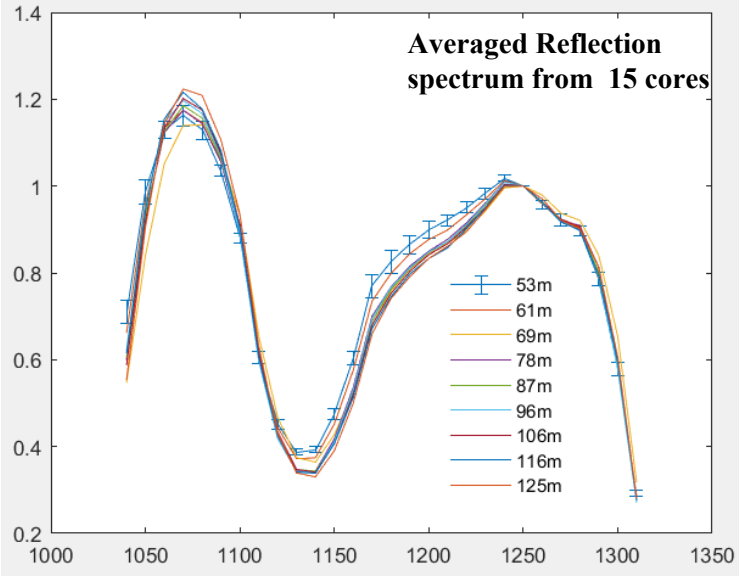
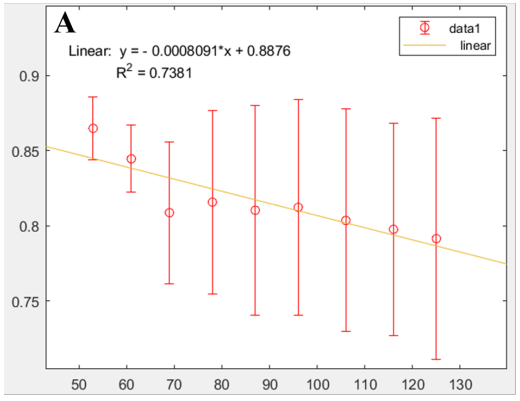
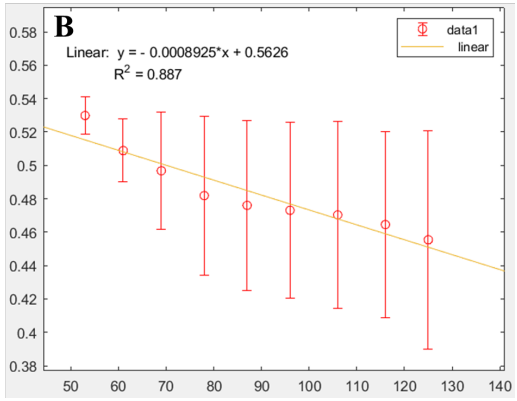


A): distance dependence of Intensity ratio (I1130/I1240)
B): distance dependence of Intensity ratio { sum (I1100nm:I1180nm)/[4X(I1070nm+I1240nm)]}





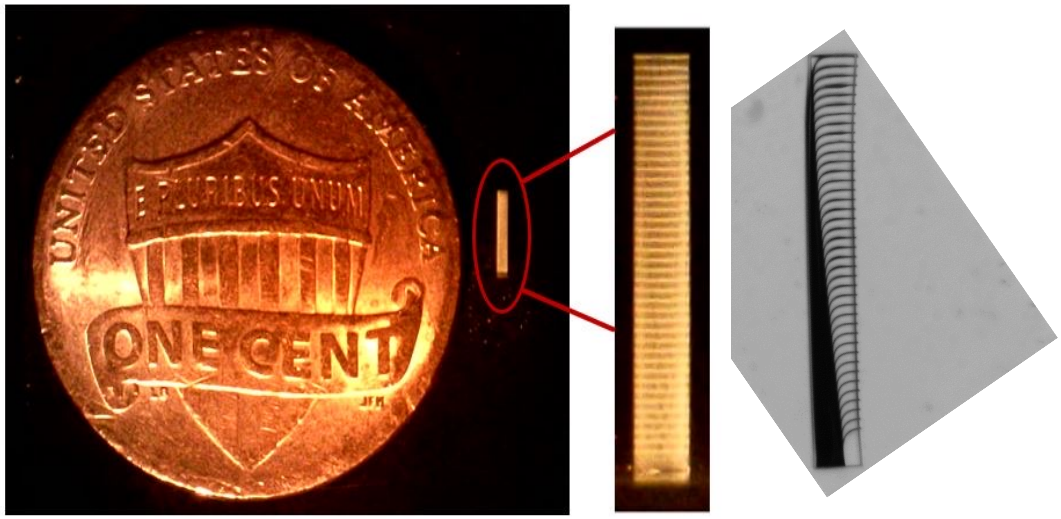
NEXT STEPS

Field Experiment in Preparation: Reservoir Evaporation

- Region with strong water vapor gradient
  - Dry up wind fetch
  - Open water
    - Saturated near surface (0.01 kg/kg)
  - Day with dry background air (0.002 kg/kg) and clear sky (common in Colorado)
  - Atm. precipitable water
- Observe growth of surface layer
  - Dry air mixes vertically as it advents horizontally
  - Moisture concentration increases with distance as evaporated water accumulates and mixes

(base for measurements)

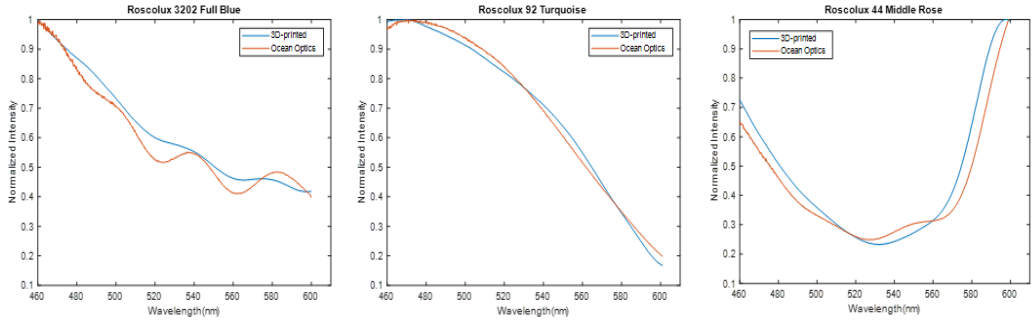
Future Integration – Past IIP Effort

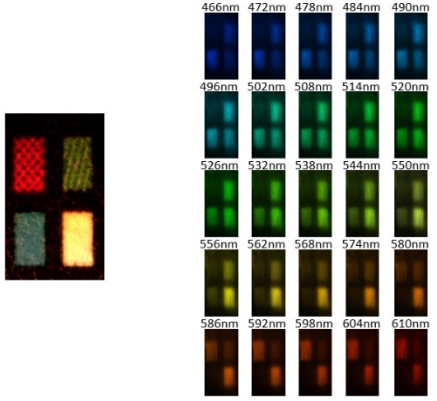


3200 (40x80) Fiber Array
2-Photon 3D printed

Submitted (Haimu Cao, Chris Flynn, Brian Applegate, Tomasz S. Tkaczyk)

Test Spectral Imaging





Summary

- VIS and SWIR TuLIPSS field imaging ready systems were packaged and are being optimized
- TuLIPSS is capable of rapid snapshot spectral imaging and sub-millisecond integration times, augmented dynamic range and conditioning of overlapping regions.
- Engineering flights demonstrate systems ability for real time field spectral imaging capabilities
- Preliminary imaging results show sufficient system sensitivity of direct water vapor detection and map with computational models
- Field water vapor experiments to map its dynamics are in preparations
- Future system generations investigate AM techniques for high level system integration