Fiber based - VIS and SWIR Snapshot Spectrometers

NASA Instrument Incubator Program

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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)

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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

Mass = 13.6 kg
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
Flight 4: Alvin

- 1000ft over city of Alvin, at approx. 50 knots
Flight 4 Field Data

Mosaic (180 images) and Composite Mosaic

TuLIPSS Composite Video

Reference Video

Selected Spectral Channel Videos

467nm  494nm  551nm  588nm  665nm

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

Reference image

Centimeter ground resolution for leaf morphological analysis
Field Spectral Unmixing

Composite Mosaic

Unmixed Mosaic

Mosaics of spectral wavelengths

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

500µs

5ms

50ms

HDR
DIRECT WATER VAPOR DETECTION
Typical SWIR Data Stack / Classification

Selected Time Points / Spectral Channels

- 1130nm
  - 0 minute
  - 1.5 minute
  - 2.5 minute
  - 5 minute
  - 10 minute
  - 25 minute

- 1200nm
  - 0 minute
  - 1.5 minute
  - 2.5 minute
  - 5 minute
  - 10 minute
  - 25 minute

- 1260nm
  - 0 minute
  - 1.5 minute
  - 2.5 minute
  - 5 minute
  - 10 minute
  - 25 minute

(3d-convolutional neural 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

Wavelength (nm)

Normalized Intensity

MODTRAN
Simulation Reference

A): distance dependence of Intensity ratio (11130/11240)
B): distance dependence of Intensity ratio \{ \text{sum} (11100nm:11180nm)/[4X(11070nm+11240nm)]\}
Averaged Reflection spectrum from 15 cores

A): distance dependence of Intensity ratio (11130/11240)
B): distance dependence of Intensity ratio (sum (11000nm:11180nm)/[4X(11070nm+11240nm)])
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 advects horizontally
  - Moisture concentration increases with distance as evaporated water accumulates and mixes

In-situ water vapor measurements will be made upwind and over lake

Dominant Wind

Dry upwind region

Dry-path

(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.