TuLIPSS: Tunable Light-guide Image Processing Snapshot Spectrometer

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Program: IIP-16
Problem to Solve

Overall Project Goals

• Develop a low-resource highly-capable tunable hyperspectral imager for a range of Earth remote sensing observations.

• Performance goals are to operate across the wavelength range 400 – 1700nm, with up to 1.2 nm spectral resolution. The spatial sampling depends on orbit/altitude but will typically range between 30m and 1000 m resolution.

• Technologies include innovative fiber optic light-guide, snapshot imaging and tunability for specific line selection and spatial/spectral pixel distribution.

Last Year Challenges

• Improve Light Throughput

• Implement a field prototype for engineering flights / targeted applications like smart farming / disaster response etc.
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)
TuLIPSS Technical Data

• Lab Demonstration, VIS Gen-I (2018-2019)
  - Integration time 50-750 ms (light throughput 2.4%-3.2%)
  - Max. frame rate, 3.4 images/second
  - Upto 32,000 cores, 60+ spectral channels 480-670 nm
  - Initial validation show good spectrum correlation with reference measurements
  - On-a-bench demonstration

• Field Instrument, VIS Gen-II (2020)
  - Integration time 0.5-10 ms (light throughput upto 60%)
  - Frame rate, 30 images/sec. (USB 3.1), 100 images/sec. (cameralink)
  - Upto 32,000 cores, 30-60 spectral channels / 460-610, 540-650, 480-670 nm (in progress), range depend on filter/prism
  - Preliminary field experiments performed – validation in progress
  - Field instrument (battery powered, laptop-control)
Throughput Improvement

Relay Systems Tested
1. 0.63x Olympus – tube lens
2. Tube lens – 0.63x Olympus
3. Doublet – iris – doublet
4. 1x Olympus – tube lens
5. 2x Olympus – tube lens
6. Tube lens – 2x Olympus

Custom 0.25, 1x optics designed – to be manufactured

Design Summary (diffraction limited):
- NA = 0.25
- FOV = 20mm
- Distortion < 0.02%
- No vignetting for all fields
- Total Axial Length = 322mm
- Corrected wavelength: 400 – 700 nm
- Camera position adjustment – focusing - for infrared wavelengths

<table>
<thead>
<tr>
<th>Configuration Magnification</th>
<th>Percentage from Fiber Bundle to sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x</td>
<td>3.2 %</td>
</tr>
<tr>
<td>0.5x</td>
<td>12.2 %</td>
</tr>
<tr>
<td>0.8x</td>
<td>13.2 %</td>
</tr>
<tr>
<td>1.25x</td>
<td>18.2 %</td>
</tr>
<tr>
<td>2x</td>
<td>38.6 %</td>
</tr>
<tr>
<td>4x</td>
<td>54.5 %</td>
</tr>
<tr>
<td>0.25x</td>
<td>14.3 %</td>
</tr>
</tbody>
</table>

Exposure:
- 500 µs

Exposure:
- 500 µs

Composite
- 475 nm
- 545 nm
- 585 nm
- 605 nm
Packaging for Field Imaging / Flights

- Flight preparation / engineering flights setup was suspended due to Covid-19
- Presented results are after resuming partial lab operations: videos / images acquired 06-03-2020 through 06-23-2020 around Rice’s Campus

Packaged TuLIPSS System

10ms exposure, global shutter at 30 frames / sec. frame rate, 31 spectral channels from 460nm to 610nm
Handheld, real-time acquisition

- **10ms exposure**, global shutter at 30 frames / sec. frame rate
- Individual image incorporates 27,530 fiber cores. 36 images used to create mosaic.
- **31 spectral channels** from 460nm to 610nm
Handheld, real-time acquisition

- Overcast – Imaging through window during storm / rainy weather
- 10ms exposure, global shutter at 30 frames / sec. frame rate
- Individual image incorporates 27,530 fiber cores.
- 31 spectral channels from 460nm to 610nm
Handheld, real-time acquisition

• **10ms exposure**, global shutter at **30 frames / sec.** frame rate
• Individual image incorporates **27,530** fiber cores.
• **31 spectral channels** from **460nm** to **610nm**
Ongoing Research / Future Plans

Radiometric System’s model

TuLIPSS Model

Light flux of a system: \( \Phi = A \Omega LT \)

- A: area of object
- \( \Omega \): solid angle accepted
- T: transmission efficiency of system
- L: irradiance

Environment parameters:
- Latitude
- Date
- Time
- Weather condition
- Sea level irradiance
- Sample surface reflectance

System parameters:
- \( D_{PM} \): diameter of pinhole in photomask
- \( D_{fb} \): diameter of fiber core
- \( T_{fb} \): transmittance of fiber bundle
- \( T_{c} \): transmittance of collimating lens
- \( T_{f} \): transmittance of focusing lens
- \( T_{p} \): transmittance of prism
- \( \eta \): Quantum Efficiency of camera

Preliminary results suggest good correlation between simulated and experimental signal levels

June 25, 2020
SWIR System Design and Assembly

1. Image mapper
2. Tube lens – mounted on translation stage ➢ defocusing for NIR/SWIR
3. Motorized filter wheel with 10 filters
4. Motorized translation stage for dispersers
5. Folding mirror
6. Imaging lens – mounted on translation stage ➢ Refocusing for NIR/SWIR
7. VIS/SWIR camera
8. Controllers for precision translation/rotation stages
9. NVIDIA computer ➢ Designed for AI applications ➢ Controls electronics ➢ Acquires images from camera ➢ Image reconstruction
10. Reference RGB camera

Tuning Implementation

Changing distance between ribbons
Summary

- VIS-Gen II TuLIPSS system was packaged and set-up for field imaging experiments
- TuLIPSS is capable of rapid snapshot spectral imaging and sub-millisecond integration times (throughput was improved by 5-20 fold depending on optics configuration)
- VIS Field imaging experiments are ongoing and TuLIPSS will be validated in number of applications including smart farming, geology tests and spectroscopy of moon flashes
- SWIR system is being integrated
- Radiometric system model is being developed
- Implementation of dynamic / tuned system for smart imaging is in progress