TuLIPSS: Tunable Light-guide Image Processing Snapshot Spectrometer

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Program: IIP-16

Problem to Solve

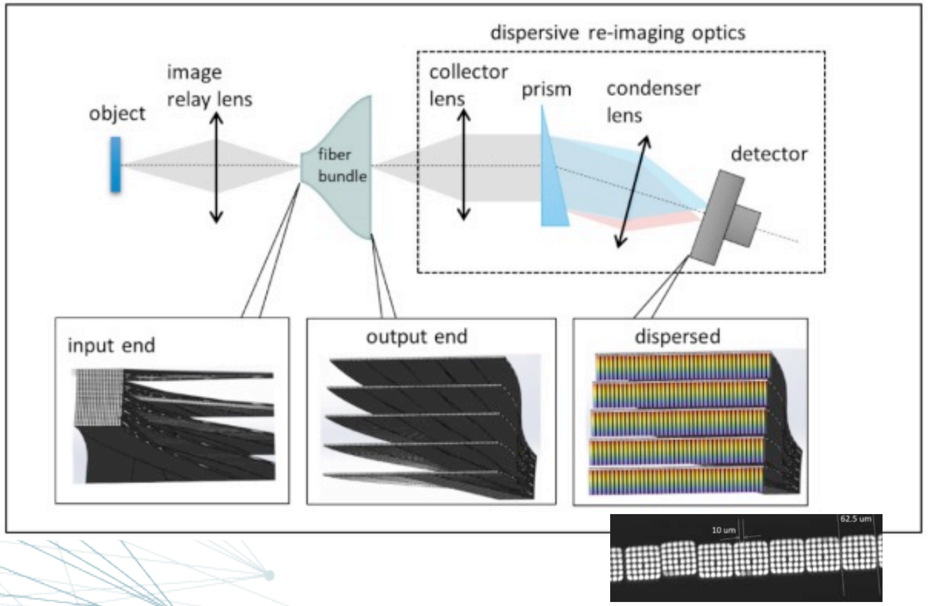
Overall Project Goals

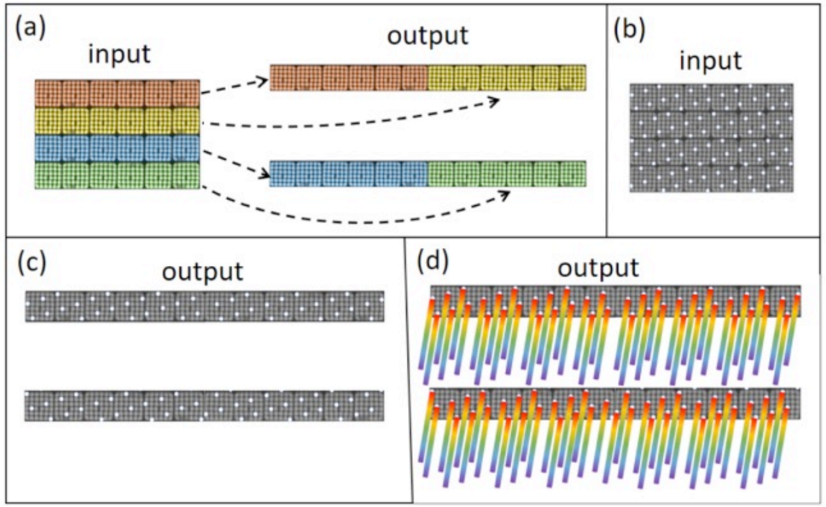
- Develop a low-resource highly-capable tunable hyperspectral imager for a range of Earth remote sensing observations.
- Performance goals are to operate across the wavelength range 400 – 1700nm, with up to 1.2 nm spectral resolution. The spatial sampling depends on orbit/altitude but will typically 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

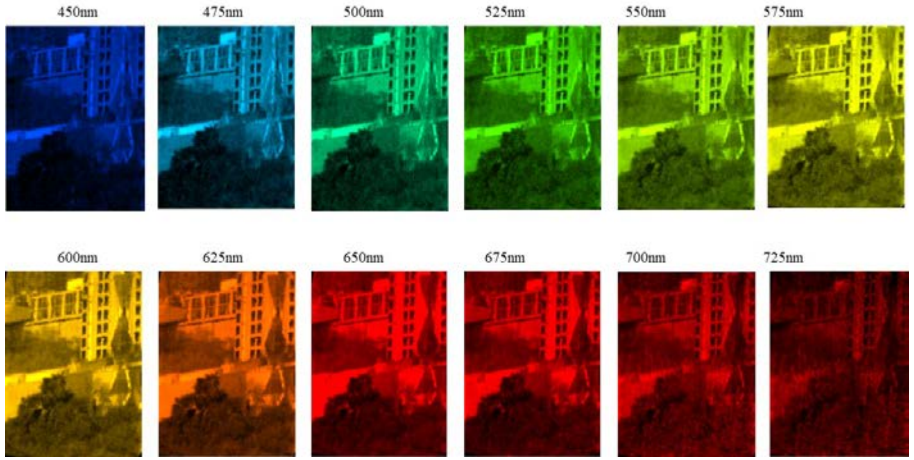
- Improve Light Throughput
- Implement a field prototype for engineering flights / targeted applications like smart farming / disaster response etc.

TuLIPSS Technology



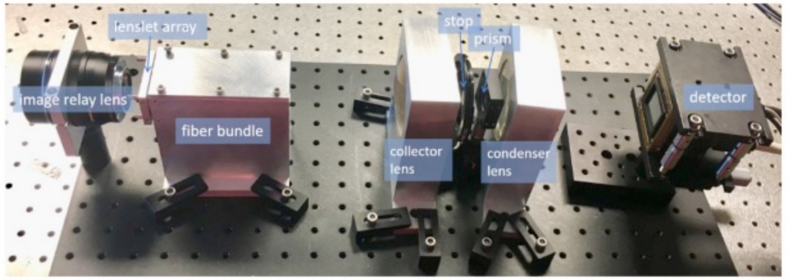


- Custom fiber light-guide reformats image to create void spaces to allow spectral cube acquisition in a single – snapshot (cube is acquired instantaneously with no-scanning)

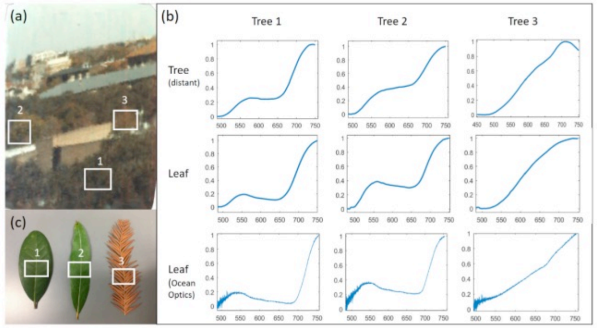


TuLIPSS Technical Data

- Lab Demonstration, VIS Gen-I (2018-2019)

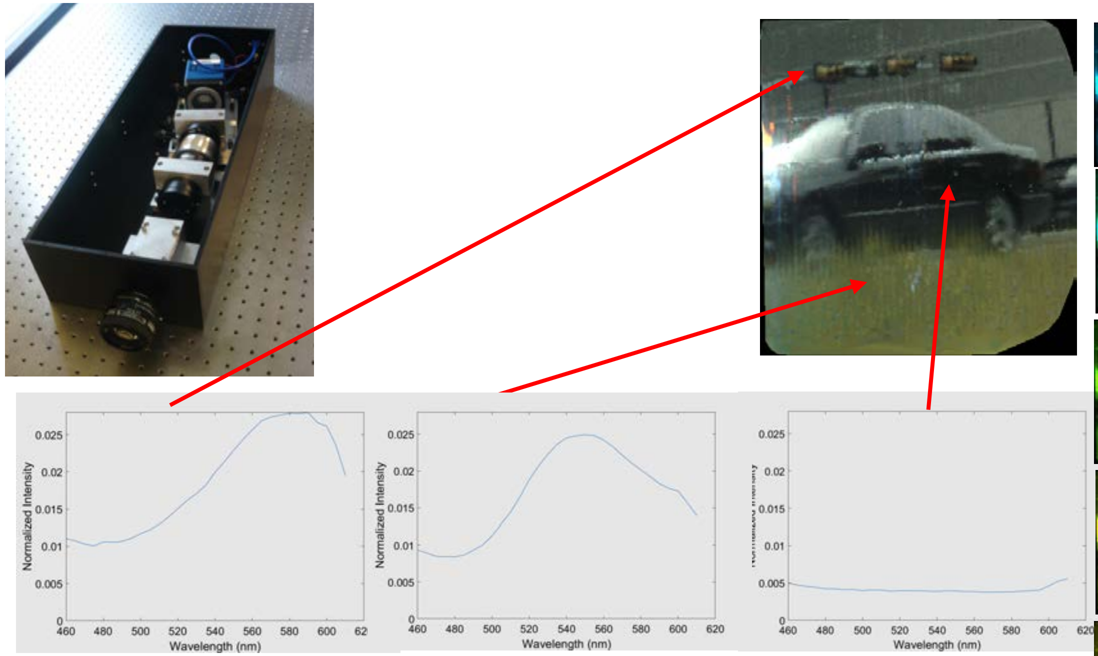


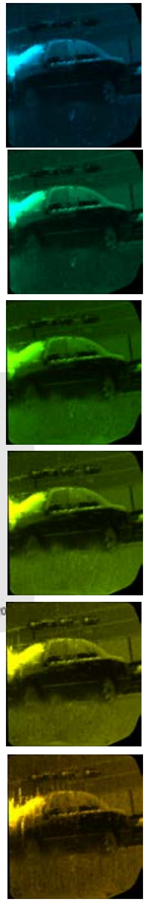
Opt. Express 27, 15701-15725 (2019)



- 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

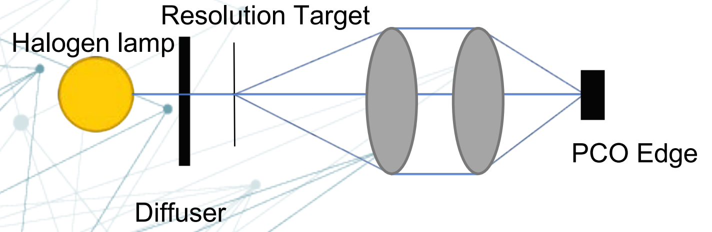
- Field Instrument, VIS Gen-II (2020)



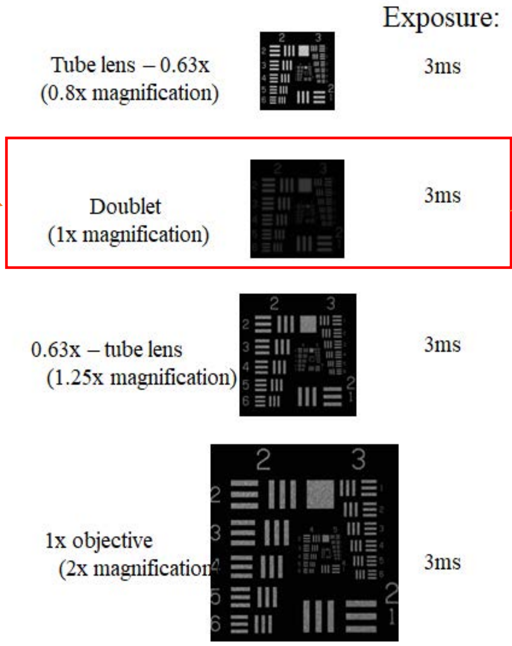


- Integration time 0.5-10 ms (light throughput upto 60%)
- Frame rate, 30 images/sec. (USB 3.1), 100 images/sec. (cameralink)
- Upto 32,000 cores, 30-60 spectral channels / 460-610, 540-650, 480-670 nm (in progress), range depend on filter/prism
- Preliminary field experiments performed – validation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

Throughput Improvement



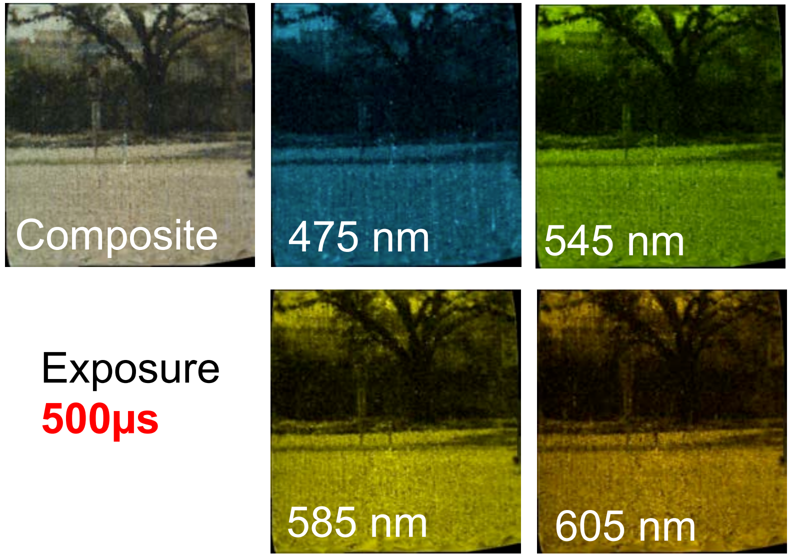
Previous Generation VIS Gen-I



Relay Systems Tested

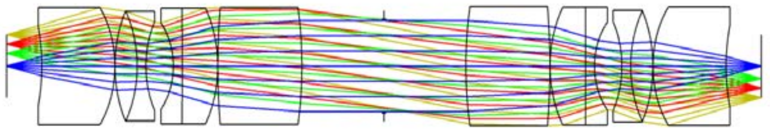
1. 0.63x Olympus – tube lens
2. Tube lens – 0.63x Olympus
3. Doublet – iris – doublet
4. 1x Olympus – tube lens
5. 2x Olympus – tube lens
6. Tube lens – 2x Olympus

Configuration Magnification	Percentage from Fiber Bundle to sensor
1x	3.2 %
0.5x	12.2 %
0.8x	13.2 %
1.25x	18.2 %
2x	38.6 %
4x	54.5 %
0.25x	14.3 %



Exposure
500µs

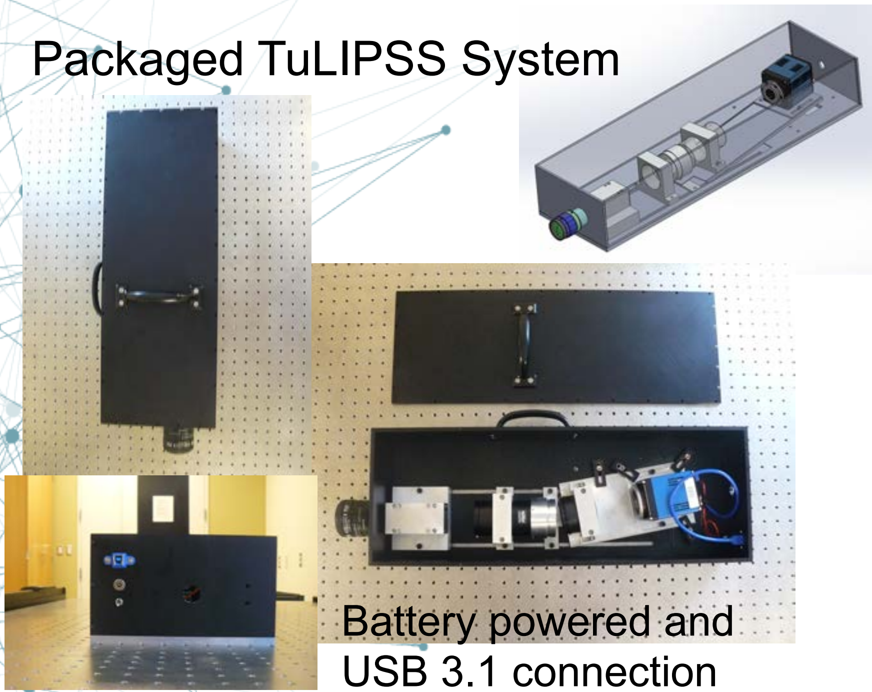
Custom 0.25, 1x optics designed – to be manufactured



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

Packaging for Field Imaging / Flights

Packaged TuLIPSS System



Battery powered and USB 3.1 connection

Getting Ready to Engineering Flights

Enabled by EAA, Pearland Regional Airport, and David Foster

- 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

10ms exposure, global shutter at **30 frames / sec.** frame rate, **31 spectral channels** from **460nm to 610nm**

Handheld, real-time acquisition

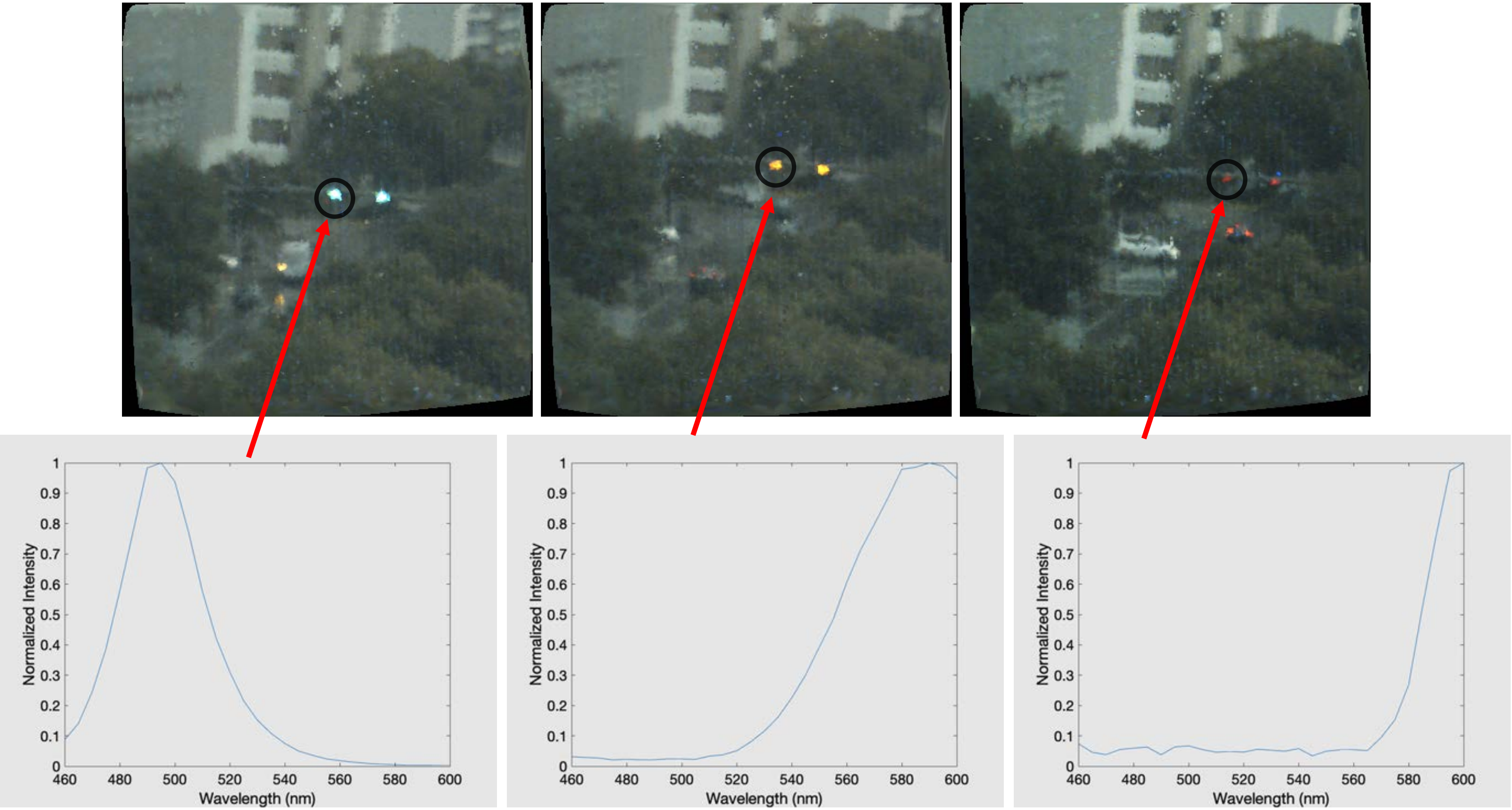

TuLIPSS Mosaic

- **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**


Mosaic Spectral Channels


Reference Image

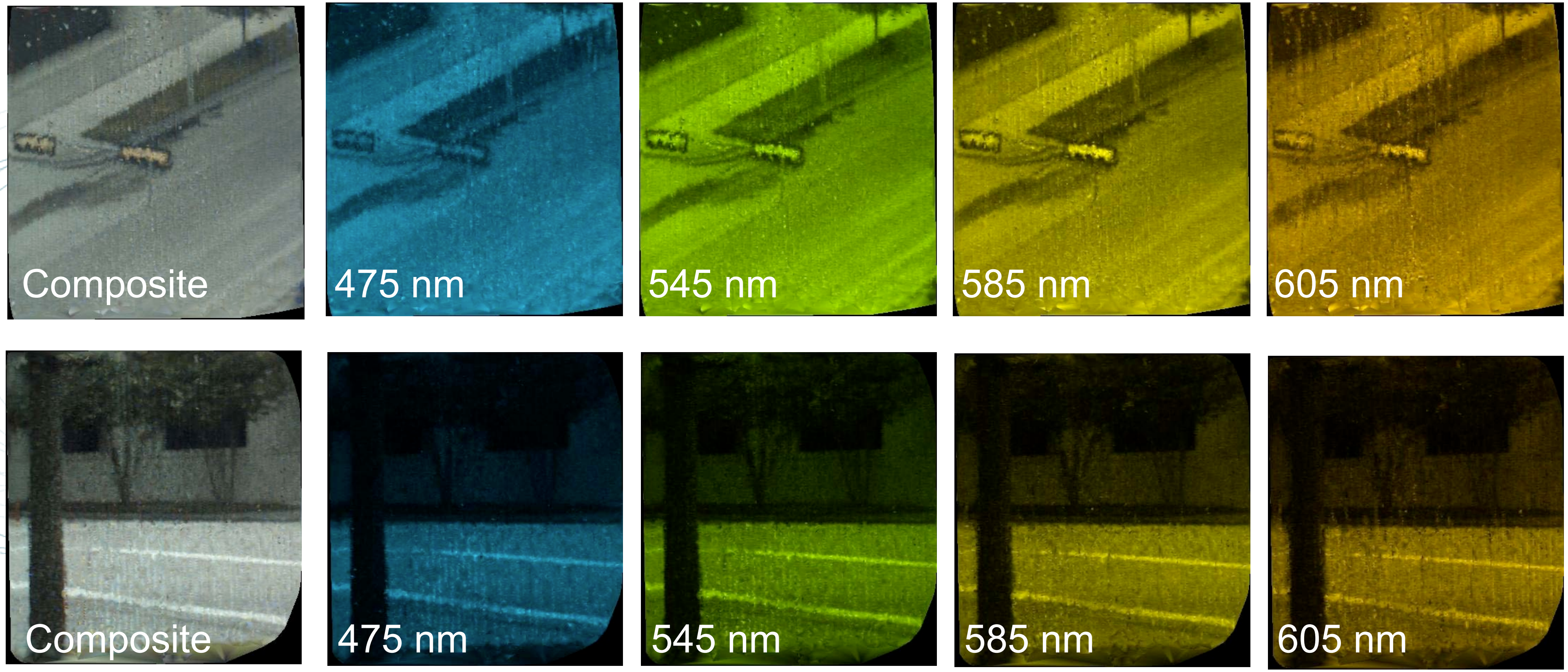
Handheld, real-time acquisition



Normalized Spectra

- **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

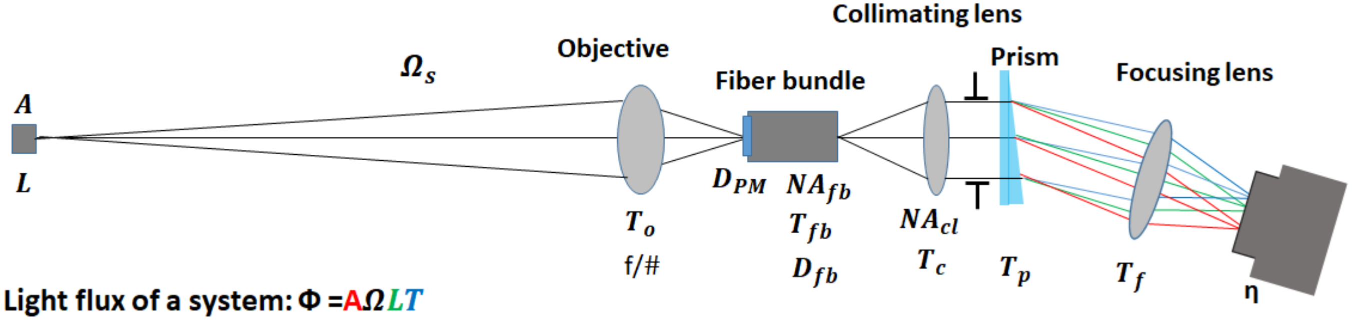


- **10ms exposure**, global shutter at **30 frames / sec.** frame rate
- Individual image incorporates **27,530** fiber cores.
- **31 spectral channels** from **460nm** to **610nm**

Ongoing Research / Future Plans

Radiometric System’s model

TuLIPSS Model



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

- A area of object
- Ω solid angle accepted
- T transmission efficiency of system
- L radiance

Environment parameters:

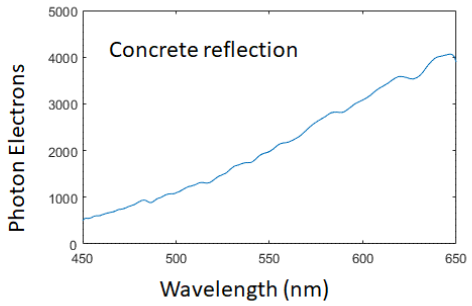
- Latitude, Date, Time → Solar zenith angle
- Weather condition, Sea level irradiance → Direct irradiance
- Sample surface reflectance

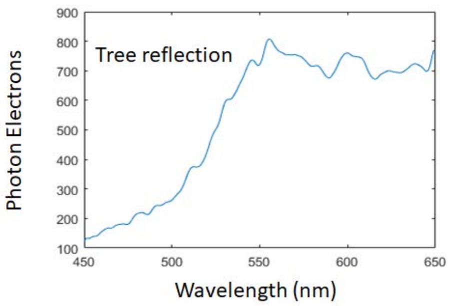
→ L radiance

System parameters:

- a pitch size of detector; M Re-magnification → A area of object
- f/# f number of objective; NA_{fb}, fiber accepted solid angle; NA_c, accepted solid angle of collimating lens; D_{PM}, dimeter of pinhole in photomask; D_{fc}, dimeter of fiber core; → Ω solid angle
- T_o, transmittance of objective lens; T_{fb}, transmittance of fiber bundle; T_c, transmittance of collimating lens; T_f, transmittance of focusing lens; T_p, transmittance of prism; → transmission efficiency
- η, Quantum Efficiency of camera; → Photo electron

f number of objective	1.4
Transmission of objective	0.7
Diameter of Photomask (um)	10
NA of fiber	0.28
Diameter of fiber (um)	10
Transmission of fiber	0.75
NA of collecting lens	0.128
Transmission of Reimaging part	0.147
Camera Quantum Efficiency	PCO_Camera
Irradiance	Sea level/Concrete/Tree
Focal Length of focal lens(mm)	144
Apex Angle of Prism	11.3
Exposure Time (ms)	10
Re Magnification	0.8
Pitch Size of Camera (um)	6.5

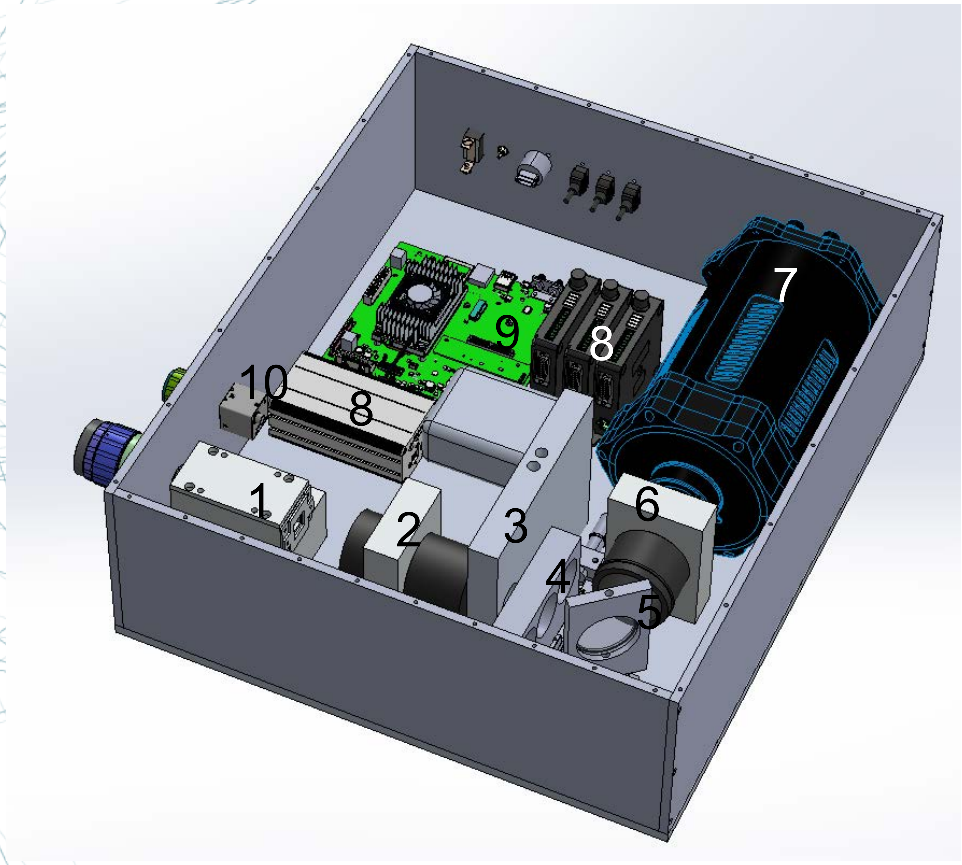




Preliminary results suggest good correlation between simulated and experimental signal levels

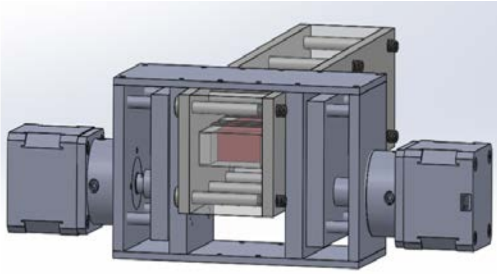
Ongoing Research / Future Plans

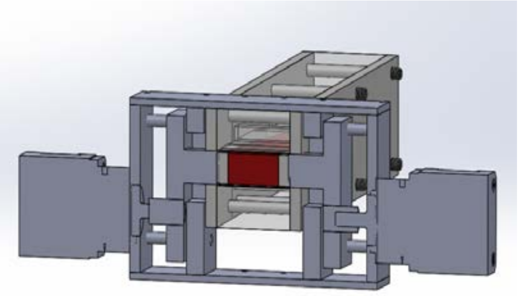
SWIR System Design and Assembly



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 intergrated
- Radiometric system model is being developed
- Implementation of dynamic / tuned system for smart imaging is in progress