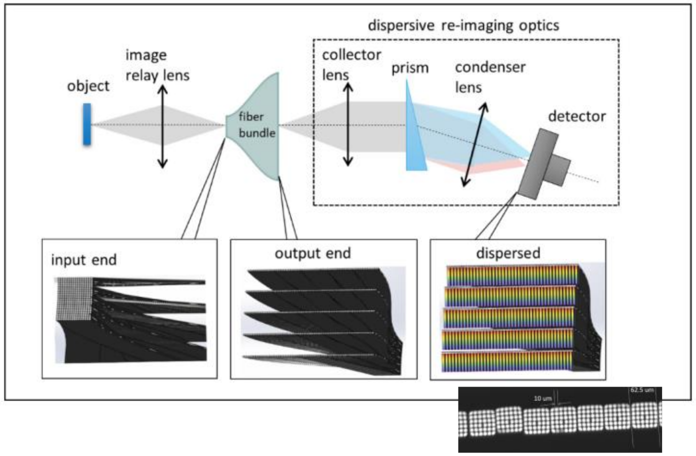
Tunable Light-guide Image Processing Snapshot Spectrometer (TuLIPSS) for Earth Science Research and Observation

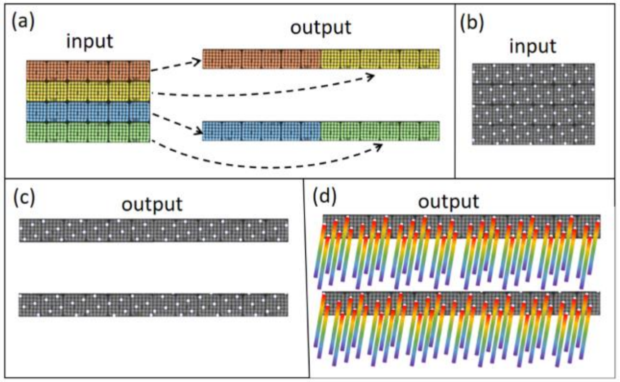
NASA Instrument Incubator Program
NNH16ZDA001N-IIP

ESTF 05/06/2021

Rice University

Principle of TuLIPSS Technology





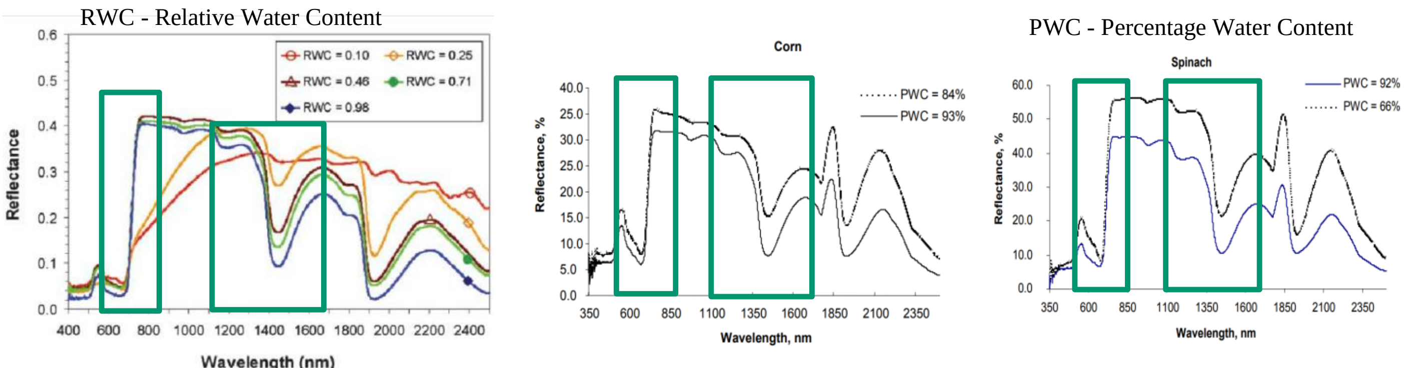
Y. Wang, M. E. Pawlowski, S. Cheng, J. G. Dwight, R. I. Stoian, J. Lu, D. Alexander, T. S. Tkaczyk "Light-guide snapshot imaging spectrometer for remote sensing applications," *Opt. Express*, 27, 11, 15701-15725 (2019). DOI: https://doi.org/10.1364/OE.27.015701.

- 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)

Tuning Spectral Range to Application

1. *VIS System – 500-900 nm –* ***Smart Farming (Water Stress & Nutrition vs Genotypes)***
2. *VIS-SWIR System - 200 nm sub-regions within 500-900 nm and 1100–1700nm –* ***Water Stress, Soil Moisture – feedback to crop assessment****, (other applications considered - Green House gas sensing)*

Referencing low altitude flights (1000-3000 ft) with ground reference and satellite data



Sample reflectance spectra for different plant genotypes subject to different levels of water stress

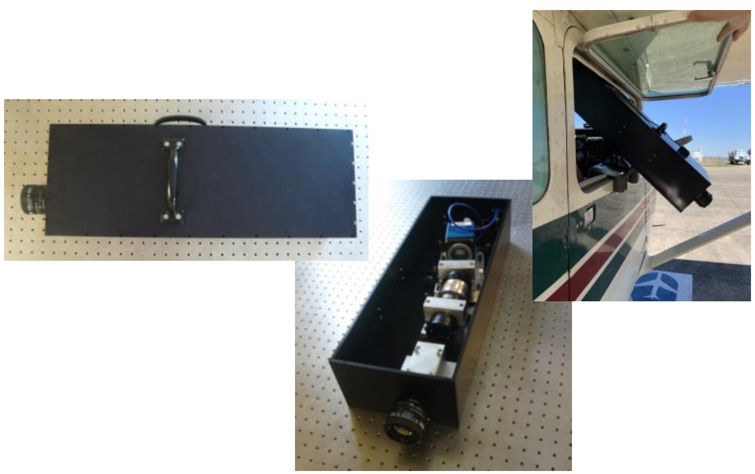
Seelig, H. & Hoehn, Alexander & Stodieck, Louis & Klaus, D. & III, W. & Emery, William. (2008). The assessment of leaf water content using leaf reflectance ratios in the visible, near-, and short-wave-infrared. International Journal of Remote Sensing. 29. 10.1080/01431160701772500.

Jones, Carol & Weckler, Paul & Maness, Niels & Stone, M. & Jayasekara, Roshani. (2004). Estimating Water Stress in Plants Using Hyperspectral Sensing. 10.13031/2013.17087.

Field Implementation Progress

02-2020

- Field VIS system integrated
  - Length: 750 mm
  - Width: 220 mm
  - Height: 133 mm
  - Mass: 6.8 kg
  - Spatial image points – 20,000-30,000 (170x170)
  - Spectral Sampling: 31+
- Preparation to flights



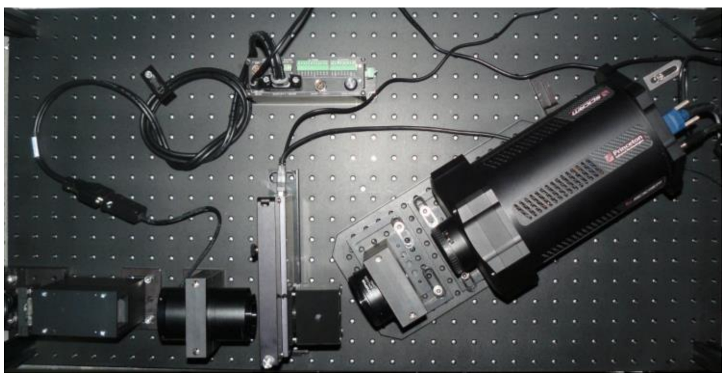
04-2021

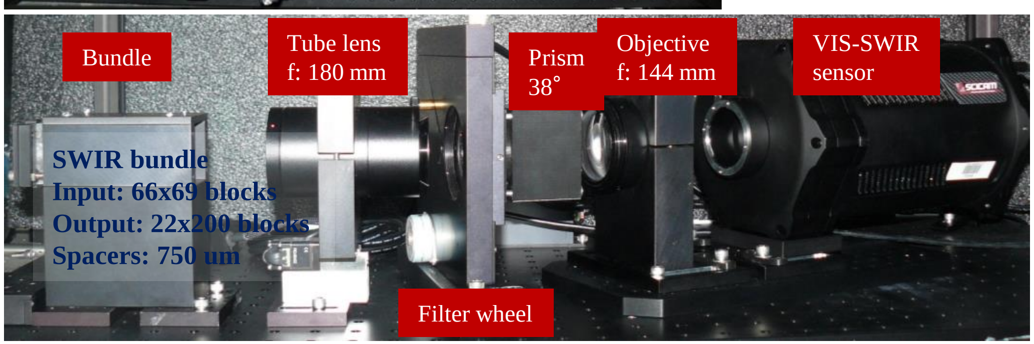
- Field VIS system optimization
  - Length: 600 mm
  - Width: 220 mm
  - Height: 133 mm
  - Mass: 6.8 kg
  - Spatial image points – approx. 63,000 (250x250)
  - Spectral Sampling: 35
- Field imaging – optimization and validation

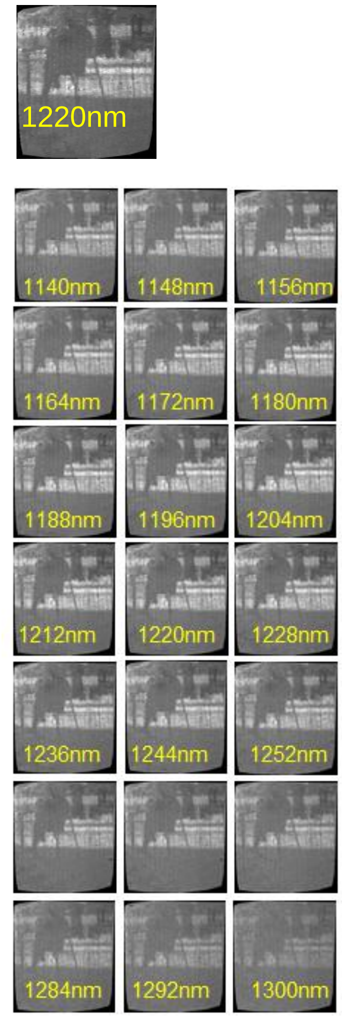
Applications flights were not performed yet due to COVID, switched to lab on the ground field experiments

SWIR TuLIPSS Configuration

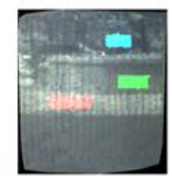
- Data cube size (mid-static)
  - Spectral: 50-54
  - Spatial: 19,200 (approx. 132x145)
- Tuning Examples:
  - Low Spectral / High Spatial
    - Spectral: 30-32
    - Spatial: 28,400 (approx. 132x214)
  - High Spectral / Low Spatial
    - Spectral: 72-75
    - Spatial: 13,400 (approx. 132x101)



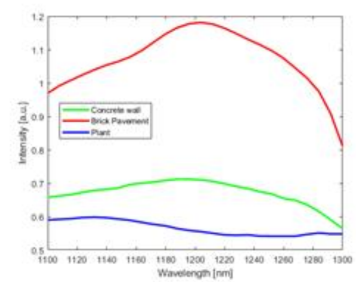




Remote Spectral Imaging 1100-1300 nm



Selected video frame for image composite

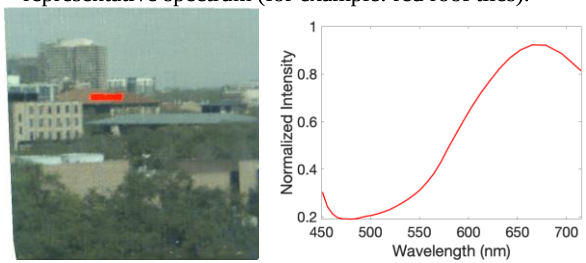


VIS TULIPSS OPERATIONAL FEATURES

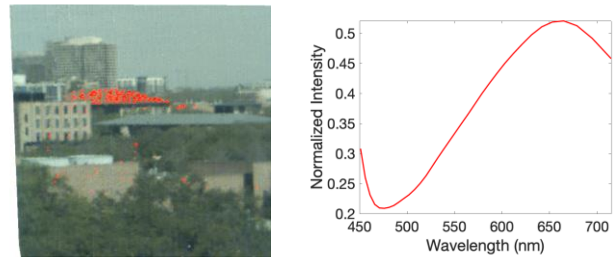
Snapshot Acquisition, Mosaicking and Unmixing

Example feature spectra

1.Extracted Spectrum from location and average for representative spectrum (for example: red roof tiles).



2. Characteristics of the spectrum is used to group similar spectra across whole scene.

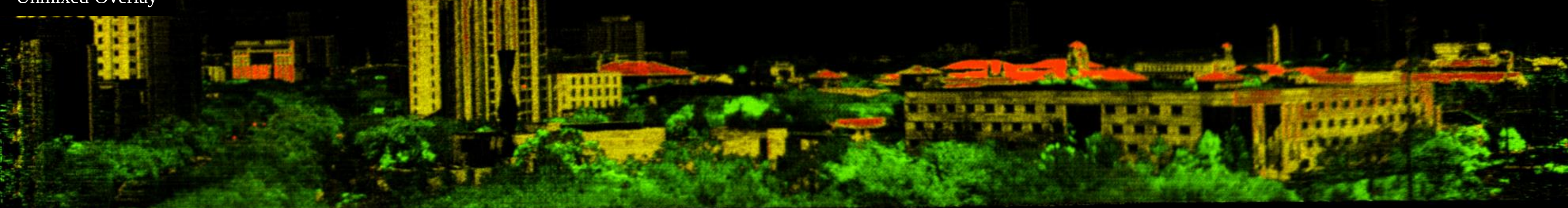


Components Unmixed:

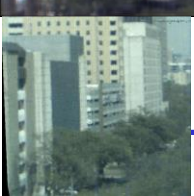
- Roof tiles
- Construction bricks
- Tree leaves cover

3. Applied spectral grouping across entire mosaic.

Unmixed Overlay

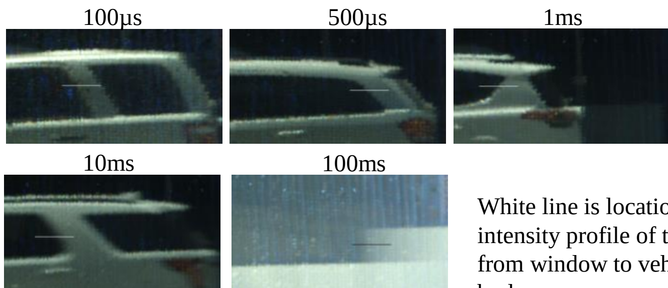


Color Mosaic



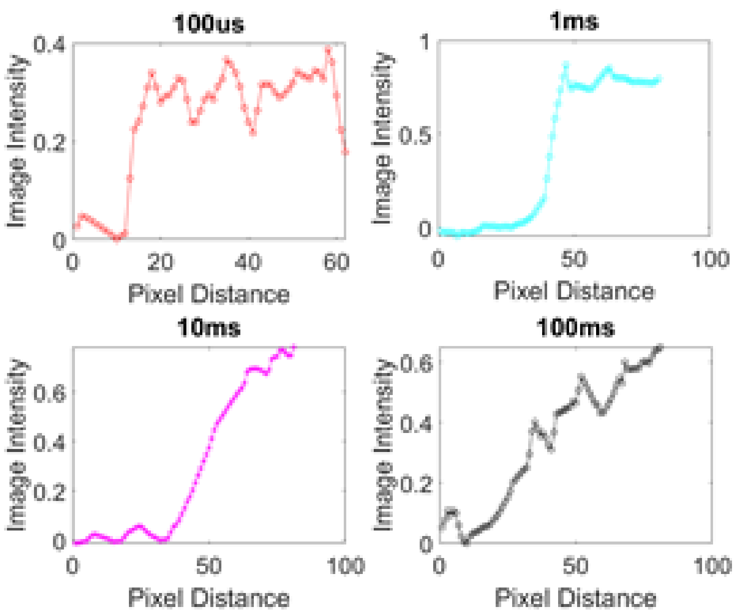
Acquisition vs Object's (Flight's) speed

Intensity Profile samples



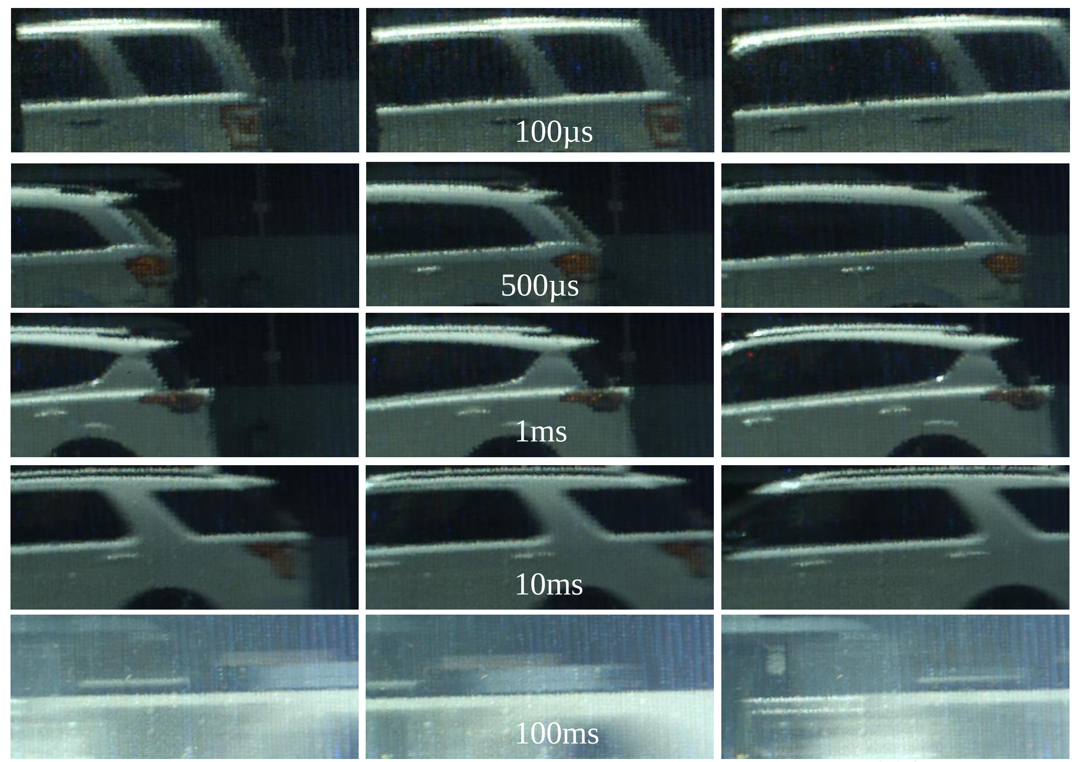
White line is location of intensity profile of transition from window to vehicle body.

Slope at transition point showcases image blur.



Examples of acquisition times for various flight conditions

Objective [mm]	Altitude [feet]	Width/pixel [ft]	Integration for pixel shift at 100 Knot, 168.8 f/sec
50	3,000	0.6	3.50 ms
50	10,000	6.0	35.5 ms
100	3,000	0.3	1.75 ms
100	10,000	3.0	17.5 ms



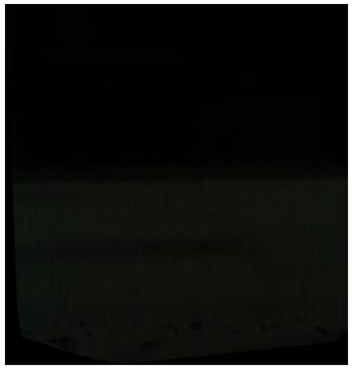
Augmented Dynamic Range

Images shown at same display brightness and scaling, single exposure images show the limitations of their dynamic range.

Composite of 3 raw images, saturated pixels replaced with shorter integration data. Respective scaling applied. The Procedure allows increased dynamic range.

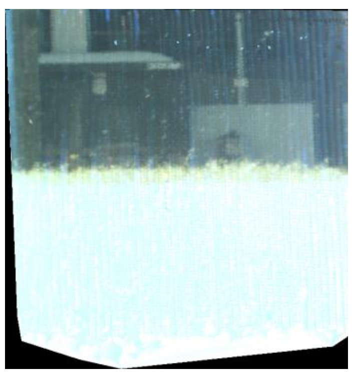
Imaging sequences through external trigger of the camera with varied, cyclical exposure, such as a repeating pattern of 500µs, 10ms, and 100ms obtain real time augmented dynamic range. In Flight experiments we plan to augment overlapping regions.

500µs

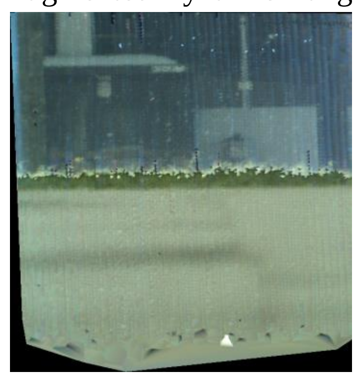


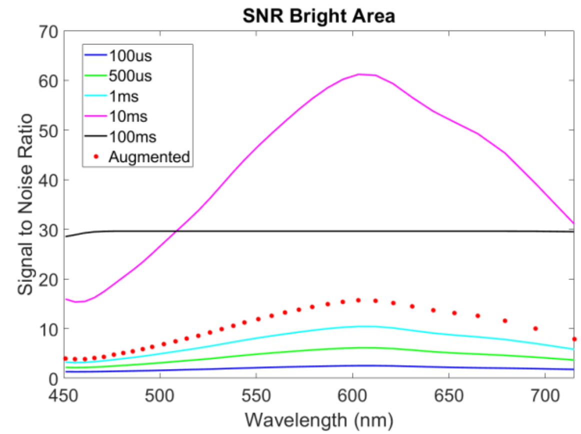
10ms

100ms

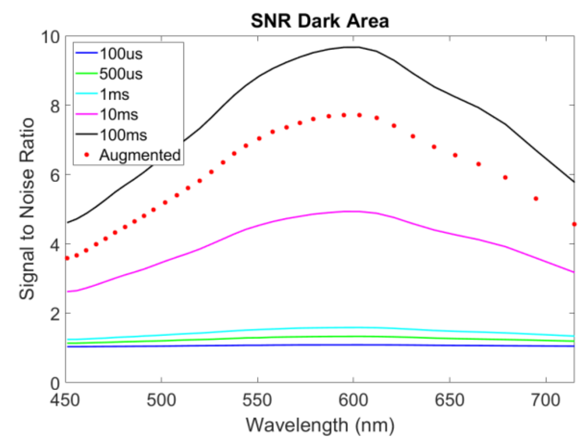


Augmented Dynamic Range





Augmented dynamic range avoids saturation of bright area's while clearly resolving dark areas



VEGETATION ASSESSMENT EXPERIMENTS

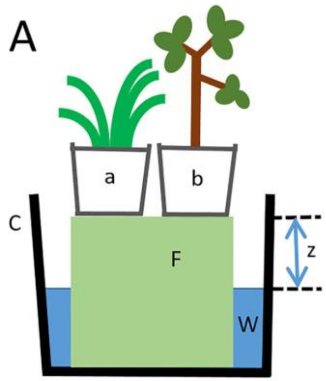
Water Plant Stress Experiment

A Simple Method for Simulating Drought Effects on Plants

Renée M. Marchin[1], Alessandro Ossola[2], Michelle R. Leishman[2] and David S. Ellsworth[1]*

[1] Hawkesbury Institute for the Environment, Western Sydney University, Penrith, NSW, Australia, [2] Department of Biological Sciences, Macquarie University, North Ryde, NSW, Australia

- Modified Snow and Tingey system drought procedure
  - Place potted plants on columns of porous foam. Different water levels produce different soil moisture conditions
  - Start all plants at Z = 1 cm (no drought condition) on December 4th and progressively lower water levels for different drought conditions over two weeks, ending on December 18th
  - After two weeks conditions represent well watered, mid drought, and severe drought groups



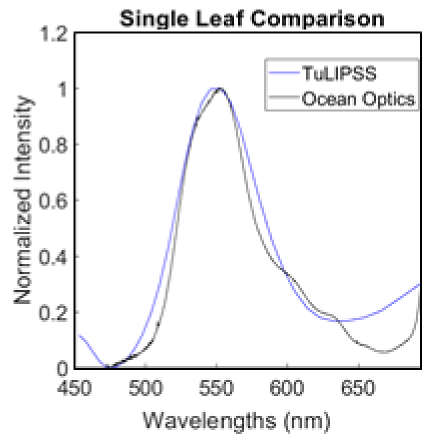
Z = 1 cm (on day 1) to 15 cm (on day 8) to 22 cm (on day 15)

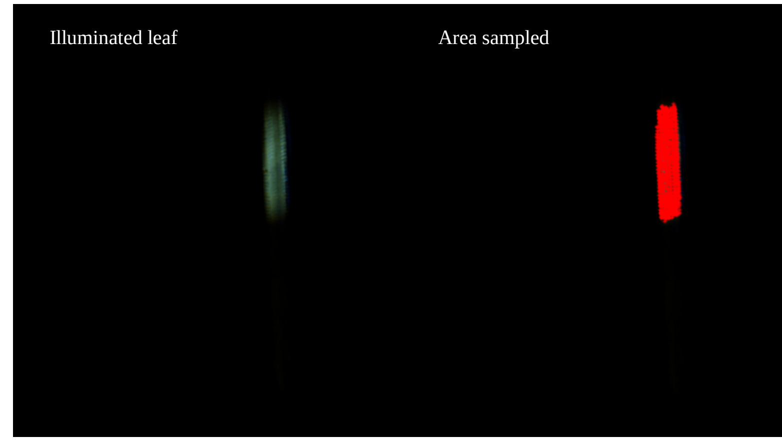
Marchin, R. M., Ossola, A., Leishman, M. R. & Ellsworth, D. S. A Simple Method for Simulating Drought Effects on Plants. *Front. Plant Sci.* **10**, 1–14 (2020).

- Plant: *Liriope muscari*
  - Type of grass used in drought study that is easily available

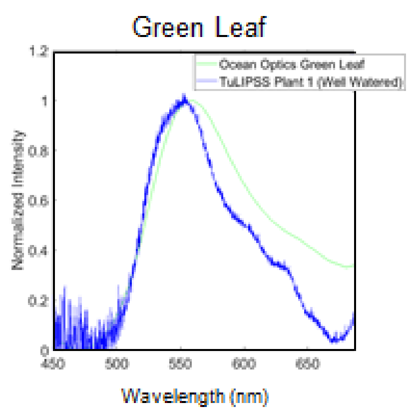
Comparison to Reference Spectrometer:

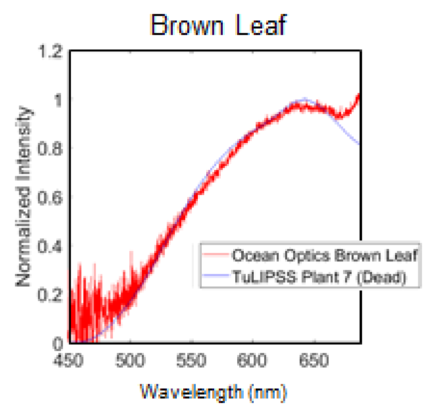
Validation of TuLIPSS spectra as compared to Ocean optics. A small illuminated area produces a similar spectrum to ocean optics.

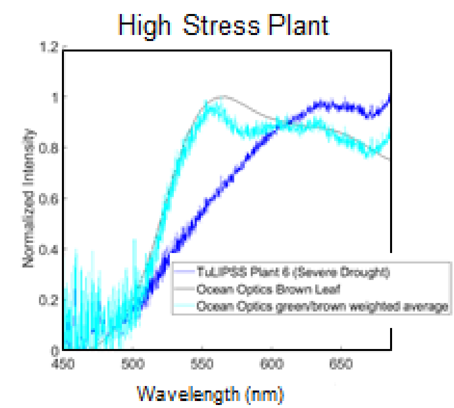




Plant-wide averages from TuLIPSS can be approximated by a weighted averaging of different spectral components found with Ocean optics.





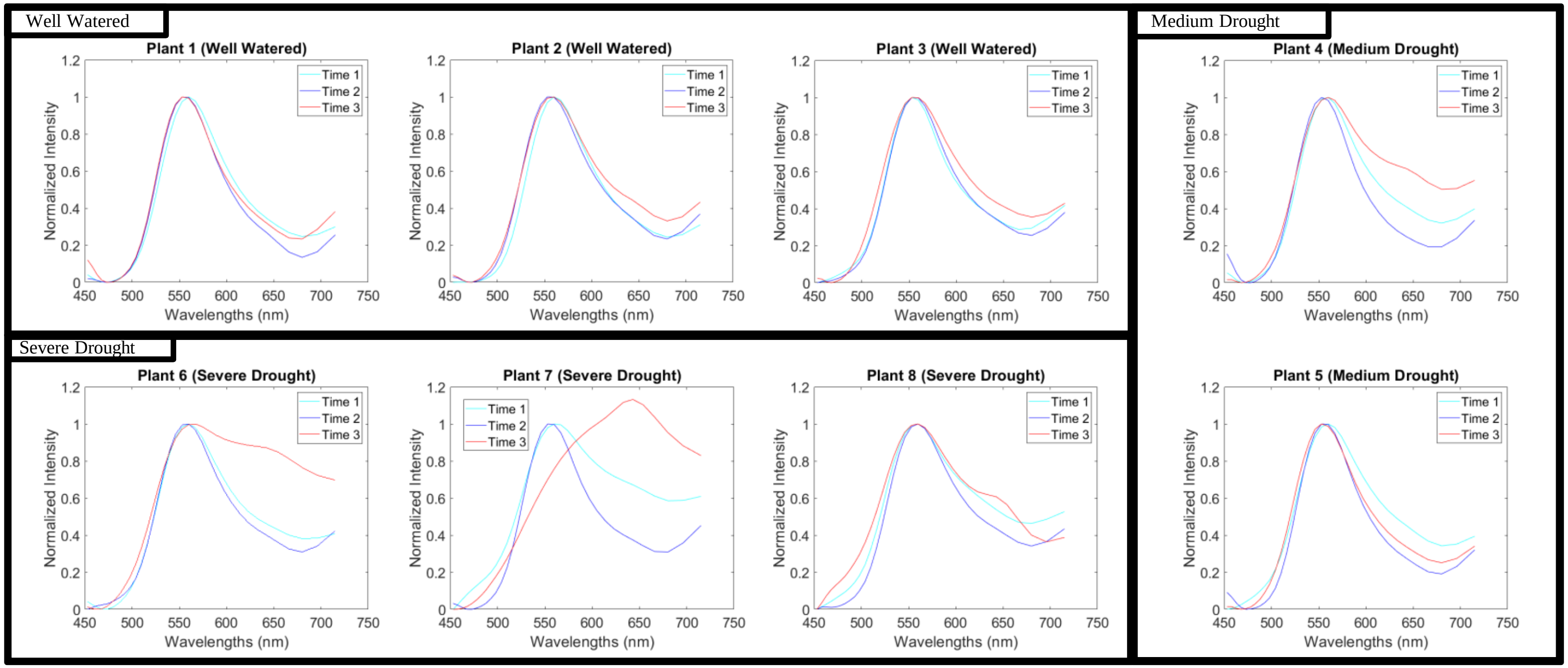


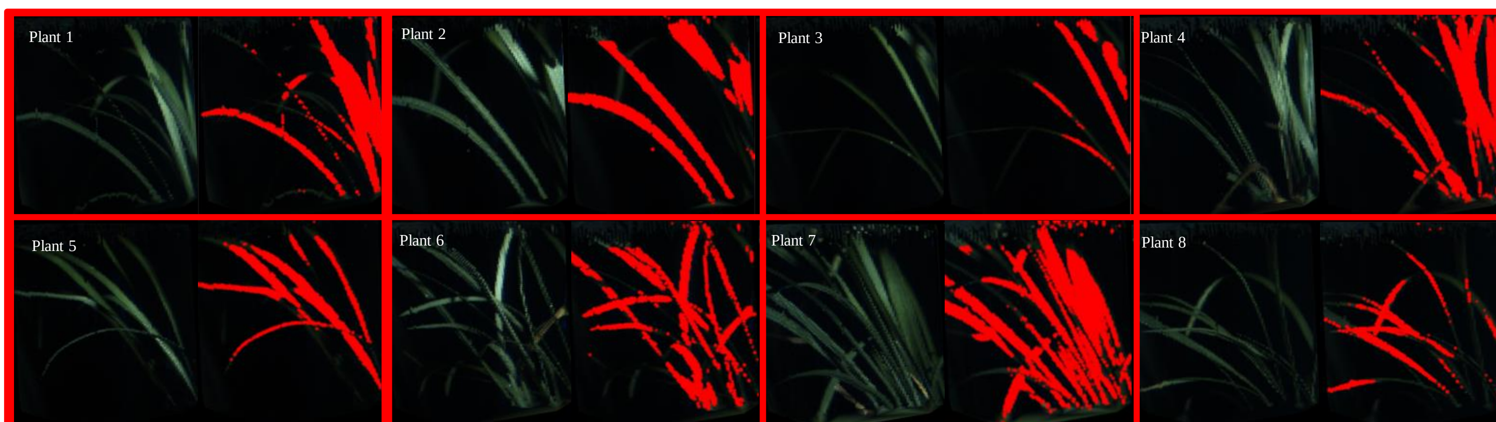
Plant Data: Over Time

Time 1 = Day 0
Time 2 = Day 14
Time 3 = Day 40

Tracking plant spectra over time shows two trends:

1. Medium stress sees a relative decrease in red region
2. Severe drought sees increase in red signal as leaves brown





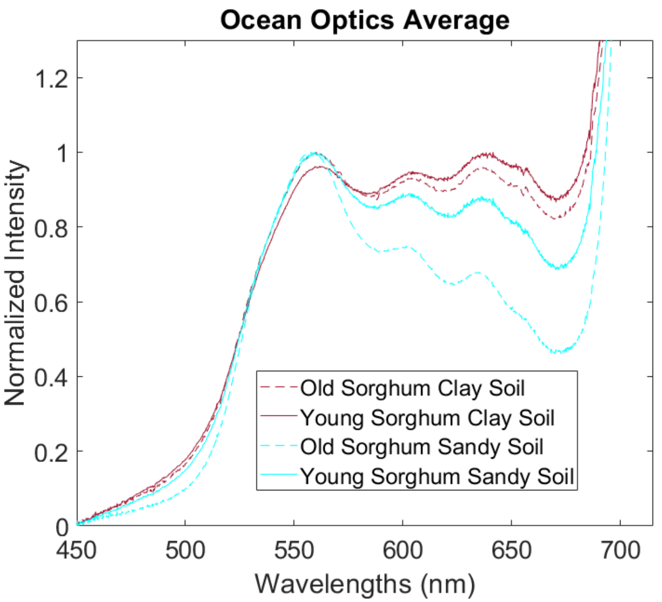
For each plant, the left image shows the reconstruction and the right image shows in red where fiber cores were sampled for spectra.

At TAMU (Experimental Session 3)

Field: Soil conditions

Sorghum in field is planted in either sand or clay, each plot has two plants started at different time points.

Sorghum growing in sandy soil at two time points featured here. Younger is on left.



Spectrum exhibits three peaks at 560nm, 603nm, and 638nm

Ocean optic signals are readings from green leaves selected from each population. Each group has three leaves which are averaged over the group.

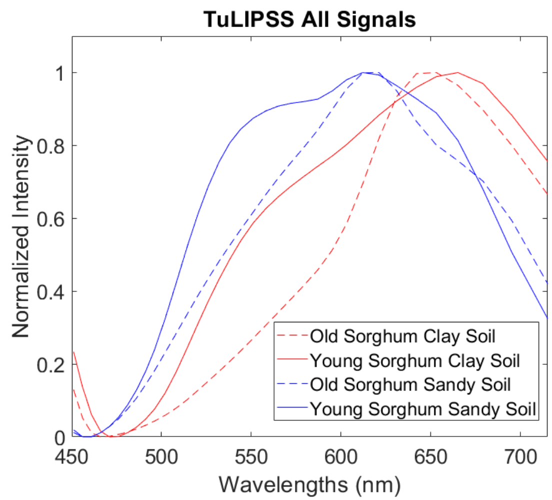
Reference Camera image of young sorghum in sandy field. One plant has leaves with many different colors and this variance will make its way into the TuLIPSS imaging

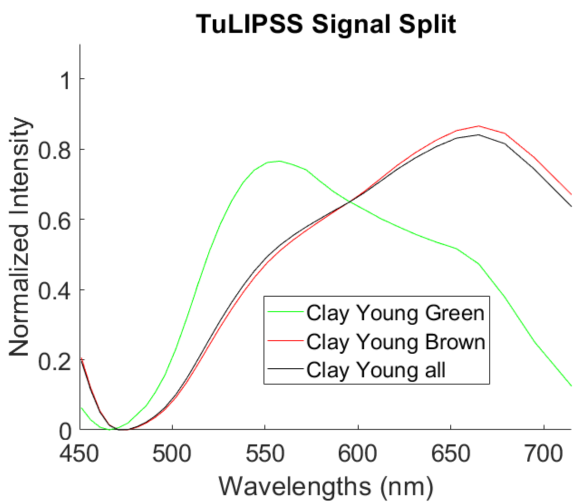
TuLIPSS Imaging Results

Signals are taken from a square in the center of the image. A threshold is set so that areas further into crop mass are not selected (see plant outlines)

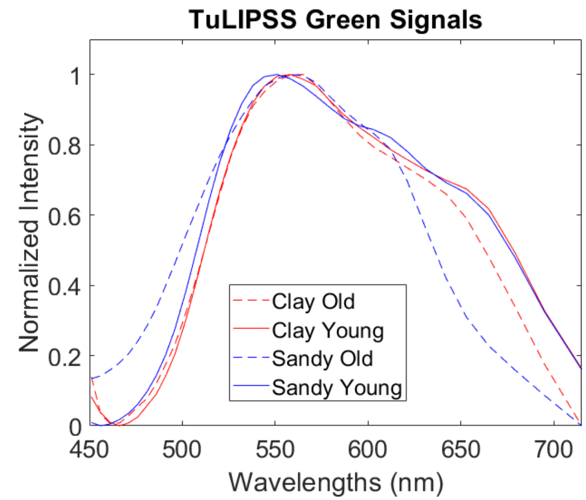
	Ratio of Green to Brown signals
Sandy (Young)	1:2.92
Sandy (Old)	1:12.70
Clay (Young)	1:14.93
Clay (Old)	1:68.53

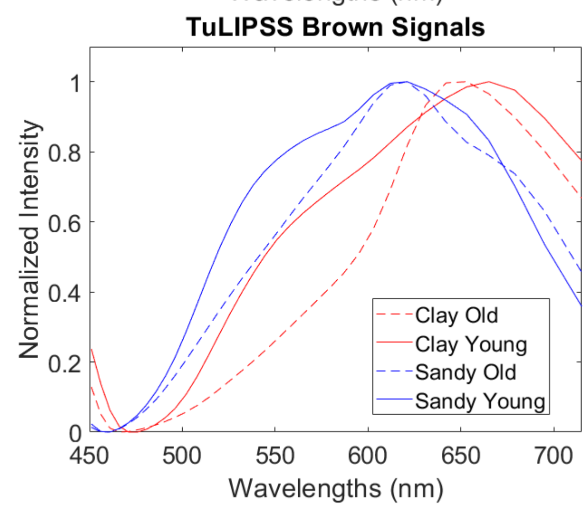
Distinct peaks at 612nm and 653nm



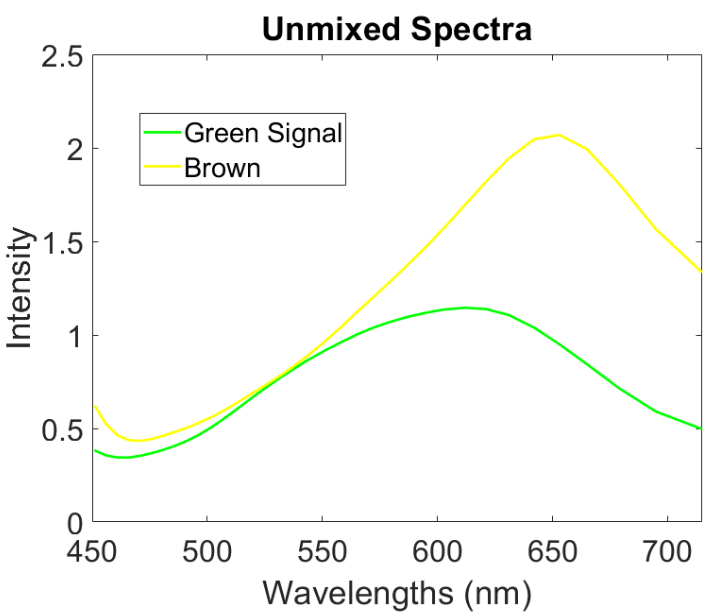


Split samples into two populations:



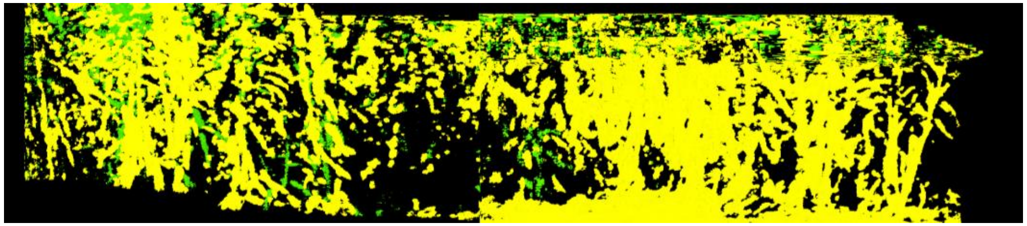


Old Sorghum in Clay Soil



TuLIPSS Color Mosaic

TuLIPSS Unmixed Mosaic



Hyperspectral snapshot imaging quickly and easily highlights the few remaining healthy plants

200 μs 500 μs 1 ms 20 ms 35 ms

Summary

- VIS TuLIPSS field imaging ready system was packaged and optimized
- TuLIPSS is capable of rapid snapshot spectral imaging and sub-millisecond integration times, augmented dynamic range and conditioning of overlapping regions.
- VIS Field imaging experiments are ongoing and TuLIPSS is being validated in smart farming application, crop water and nutrition stress
- SWIR system is being tested for field applications
- Radiometric system model was developed and serves as a design and configuration guidance.
  - System model App
    - Allows to Simulate/Predict signal levels for different land covers and system configurations
  - Validated the model
    - based on the absolute irradiance measurements
    - based on surface reflectance and global irradiance against TuLIPSS measurements