RIT | Chester F. Carlson Center for Imaging Science
Digital Imaging and Remote Sensing Laboratory

Annual Report

2019-2020

Foreword

Carl Salvaggio

Foreword

Well, that was an "interesting" end to our current fiscal year …

As my second year as the Director of the Digital Imaging and Remote Sensing Laboratory draws to a close, I continue to be astounded by the great collection of researchers that make up this organization. In the face of the ongoing COVID-19 pandemic, our lab continues to flourish. Watching this fine group of researchers adapt to our new way of operating has impressed me; learning about the virus's existence, watching our University close its doors and pivoting to take all of our classes online, cutting off access to all on-campus laboratory activities, coming up with a safe and timely reopening plan with New York State for our essential research, and getting all required access back over the closing three months of the fiscal year impressed me. It was amazing what we were able to accomplish working together.

I want to thank the entire RIT community for coming together to allow our laboratory to not miss a beat and continue to conduct our world-class research and continue to mentor our undergraduate and graduate student researchers in the manner that we have always prided ourselves on. Special thanks to the Center for Imaging Science director, David Messinger, the dean of the College of Science, Sophia Maggelakis, our Vice President for Research, Ryne Raffaelle, and our director of Government and Community Affairs, Deborah Stendardi for all that they did to work with us and the State to get our doors back open and allow us to operate safely and efficiently in our new "world". We owe a large debt of gratitude to our administrators.

This year continued to be exciting as RIT remains on its' path to becoming a national research university. The past two decades have included dramatic growth in our laboratory to the point where we are now 9 tenured/tenured track faculty across multiple schools, 3 research faculty, 15 full-time research staff, 5 support and administrative staff, and over 40 undergraduate and graduate students supporting our vast research portfolio. We all believe that we are now at the beginning of our next stage of evolution of this group, and see exciting years in all of our futures.

We were joined this year by four new researchers, Byron Eng, Rehman Eon, Phil Salvaggio, and Michael "Grady" Saunders. This growth was enabled by exciting opportunities created by our DIRSIG and NASA/USGS researchers. These new lab members have all hit the ground running and are already making huge contributions to our laboratory's mission. We could not be happier to have each of them become part of the DIRS family. We are looking to grow even more by pushing into a new research thrust, synthetic aperture radar, and are in the midst of a search for researchers and faculty in this area.

This year we have seen new work start with the Office of Naval Research (ONR), the United States Air Force (USAF) and Kitware, Inc, the L3Harris Technologies, Inc, the United States Department of Energy (DOE), the United States Department of Agriculture (USDA), Moog, Labsphere Incorporated, the National Aeronautics and Space Administration (NASA), the National Reconnaissance Office (NRO), the National Geospatial-Intelligence Agency (NGA), and the United States Geological Survey (USGS). We are excited to be working with some of these organizations for the first time and continuing our research relationships with many of our favorite long-term sponsors.

To be the Director of this laboratory is truly a gift. Having such a collection of researchers, principal investigators, and faculty who all are all at the top of their disparate fields - all working together to share their kind of remote sensing science, elevates each of us to do things we could not do as individuals. We are all very lucky to be part of the DIRS family.

With my warmest regards,

Research

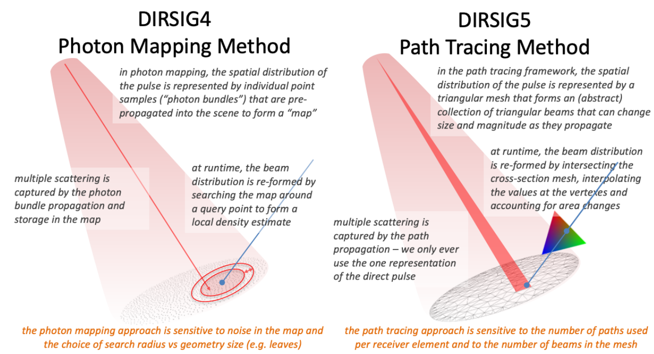
The following represents selected projects conducted by the students, research staff, and faculty of the Digital Imaging and Remote Sensing Laboratory during the 2019-2020 academic year. These projects are in various stages of their lifecycle and are representative of the widely varying interests and capabilities of our scientific researchers.

DIRSIG5 Active Imaging (LiDAR) Development

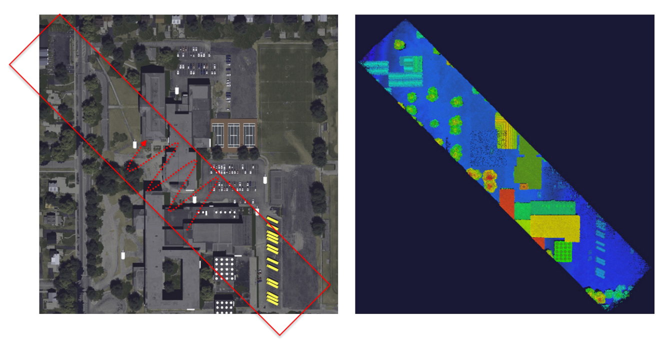
Team: Adam Goodenough and Scott Brown

One of the most complete end-to-end modeling capabilities to model with DIRSIG4 was active electro-optical (EO) laser radar systems. This capability was focused on modeling pulsed, incoherent detection systems and supported multiple detection schemes. The DIRSIG4 model included a transmitter description that supported flexible options for describing the spatial, spectral and temporal shape of the transmitted. The receiver side of the system supported both single detector and 1-D or 2-D detector arrays with backend models for linear-mode avalanche photo-diode (LmADP), Geiger-mode avalanche photo-diode (GmADP) and multi-channel photo-multiplier tube (PMT) detection schemes. The major limitation of the model was that it required the user to correctly configure a complex set of parameters related to the bi-directional beam propagation method (a time-of-flight enhanced version of "photon mapping"). In addition to being critical for correctly modeling these systems, the values of these parameters could also have a huge impact on computational performance.

The initial releases of DIRSIG5 did not support the lidar modality because the initial radiometry core implementation did not include the code to model pulsed sources and to track time-of-flight along the rays used in the new path tracing algorithm. Over the past few months, that work has been initiated and completed. Inspired by an approach developed in DIRSIG5 to model the propagation of sunlight into the water, a new beam propagation approach was developed that abandons the old photon mapping method and utilizes a geometric mesh description to represent the beam (see image below). In addition to eschewing the complex configuration of the old photon mapping approach, the new method is more compact in terms of memory usage and simplifies the tracking of multiple pulses in flight for higher altitude and/or higher pulse repetition rate (PRF) systems. Unlike the parameter manipulations required with the DIRISG4 photon mapping approach, the new path tracing approach utilized in DIRSIG5 for all modalities provides the end user with a direct computational performance vs. radiometric fidelity control knob. This makes the correct and efficient operation of the new model straight forward, simplifies end-user training and reduces technical risk.



To leverage this new pulsed beam representation capability in the core, the BasicPlatform sensor plugin (which provides the backward compatibility for DIRSIG4 era sensor descriptions) was updated to support the historic mono-static and bi-static lidar system descriptions featured in the 15 different lidar specific demo scenarios available to the users. At this time nearly all of these demos are working with DIRSIG5 and new demos for a user-defined beam profile and a multi-static (multi-vehicle) collection scenario have been created. The model is now able to model large area collections (including the one pictured below) faster than DIRSIG4 due to the simplified beam propagation and more efficient multi-bounce radiometry, the ability to leverage multi-threaded execution and (eventually) the ability to leverage an MPI enabled execution environment.



The October 2020 quarterly release of DIRSIG was the first general release to include the initial lidar support and the capabilities and maturity of this modality continue to evolve during late 2020 and early 2021.

High-fidelity Scene Modeling and Vehicle Tracking Using Hyperspectral Video

Principal Investigator: Matthew Hoffman

Team: Anthony Vodacek, Chris Kanan, Tim Bauch, Don McKeown, Aneesh Rangnekar, Zachary Mulhollan

Project Description

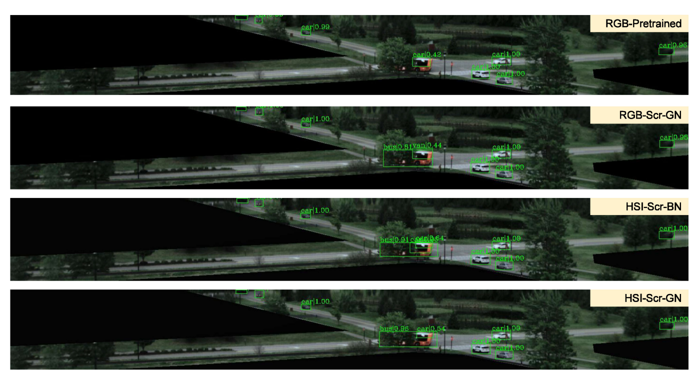
The ability to persistently track vehicles and pedestrians in complex environments is of crucial importance to increasing the autonomy of aerial surveillance for the Air Force, Department of Defense, homeland security, and disaster relief coordination. Non-visual surveillance is particularly beneficial for when dealing with airborne collections, where the number of pixels on a target is relatively small and thus spatial features are not sufficient to identify a target. Spectral cameras have the ability to leverage additional phenomenological features to enhance robustness across varying environments.

This project involves 1) collecting and annotating novel hyperspectral datasets of vehicle and pedestrian movement that will be released to the community through the Dynamic Data-Driven Applications Systems (DDDAS) website, 2) developing a DDDAS framework for efficiently extracting and exploiting information from this large dataset to facilitate different applications, including real-time tracking and understanding actions at a meet up of different targets of interest and 3) developing a new capacity for DIRSIG to support dynamic, online construction of physics-based scene models.

Simulated DIRSIG parking lot scene (center) using paint spectral signatures from a HSI drone collect of cars in the RIT parking lot (surrounding images). The collected paint signatures are being used to increase the DIRSIG vehicle paint library and allow improved generation of training data for target detection and tracking algorithms using HSI.

Project Status

Multiple data collections have taken place including hyperspectral video collected from the rooftop of the Carlson building. This is one of the first hyperspectral video scene for tracking vehicles. In addition drone collect of vehicle paint signatures was conducted on the RIT campus. This collect is being used to provide a larger database of paint signatures, including spectral variance information, to the DIRSIG platform. A larger vehicle signature database will increase the utility of DIRSIG for generating training data for deep learning applications. A mount has been constructed for the hyperspectral video camera to go on moving vehicles and we continue planning an airplane collection.



Output of vehicle detection results on frame of hyperspectral video taken from the roof of the Chester F. Carlson building at RIT. Detections are given by different convolutional neural network algorithms. The top two use only the traditional RGB information from the image, while the bottom two are showing the confidence in predictions using networks designed to incorporate hyperspectral data.

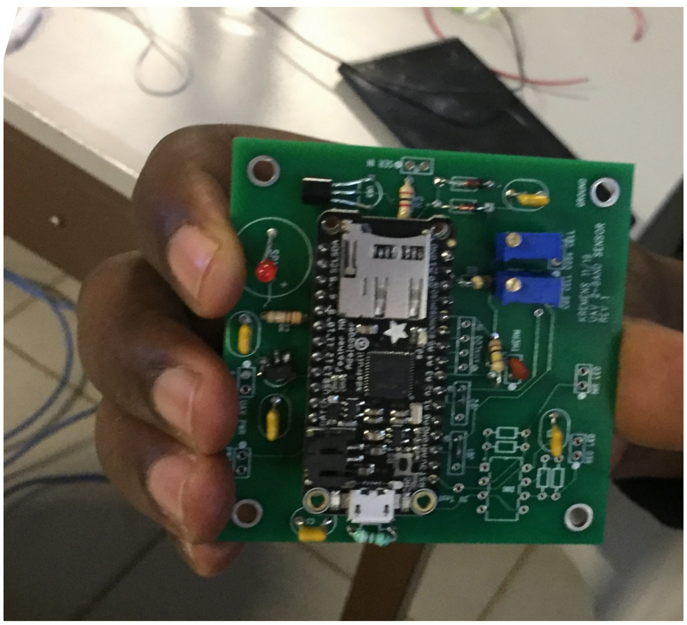
Drone Training

Principal Investigator: Anthony Vodacek

Research Team: Robert Kremens, Tim Bauch, Nina Raqueno

Project Description

With funding from IEEE Geoscience and Remote sensing Society, Vodacek along with staff members Tim Bauch and Nina Raqueno delivered a drone sensing workshop at the African Center of Excellence in Internet of Things at the University of Rwanda in Kigali, Rwanda, in November 2019. Participants from the University of Rwanda and from Jomo Kenyatta University of Agriculture and Technology and the Regional Centre for Mapping of Resources for Development (RCMRD), both in Nairobi, Kenya, gained experience in assembling and deploying sensor kits suitable for drone platforms. The sensor kits were developed by Research Professor Robert Kremens.



A workshop participant shows their completed sensor kit.

Nina Raqueno working with workshop participants at the University of Rwanda to perform calibration of light detecting sensor kits.

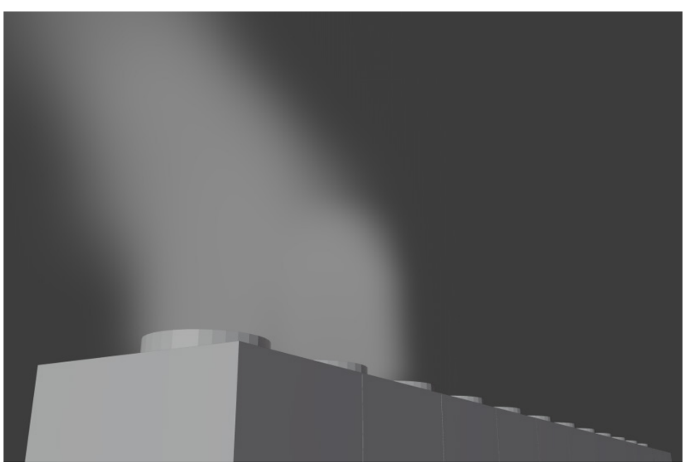
Condensed Water Vapor Plume Volume Estimation

Principal Investigator: Carl Salvaggio

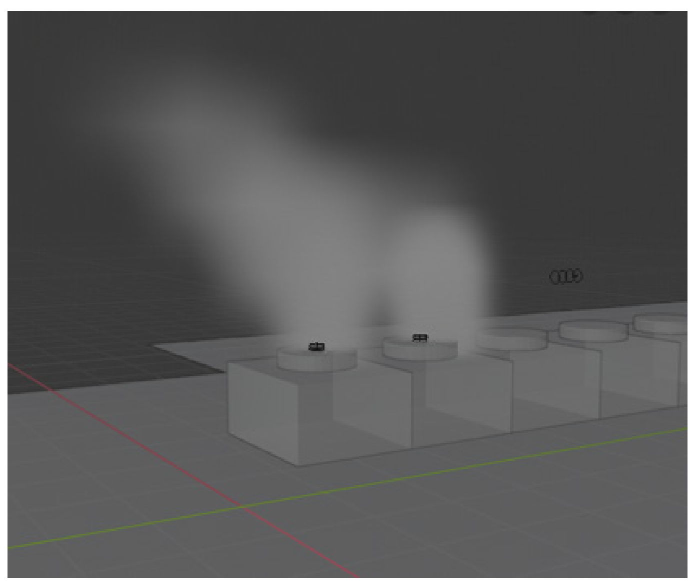
Team: Ryan Connal, Tim Bauch, Nina Raqueno, Meg Borek

Project Description

This project focuses on utilizing imagery to develop methods of analysis to calculate the volume of the condensed water vapor plume from industrial mechanical draft cooling towers. The primary objectives include determining which spectral regions could be utilized to view the spectral and spatial characteristics of such plumes, which would assist in the research and development of methods for 3D reconstruction with multi-view imaging. The former involves imaging condensed water vapor plumes against various backgrounds to observe potential contrast as well as significant spatial features which could be utilized in 3D reconstruction algorithms. Water vapor plumes emit energy so collecting imagery in the longwave infrared was pursued for combination with the spatial information from visible sensors. However, other spectral regions should be considered since water vapor plumes could display prominent features and information across the electromagnetic radiation spectrum. With longwave sensors, midwave and shortwave along with visible and near-infrared will be deployed. This aspect of the research incorporates modeling across MODTRAN to simulate various atmospheric conditions with varying liquid cloud water density and air temperature within the plume boundary.



The process of 3D reconstruction for a plume, whose physical structure is constantly changing, requires instantaneous capture from a multitude of sensors at various positions around the cooling towers. Leveraging imagery with optical distortion accounted for is imperative in the process of stereo reconstruction, so a cheap methodology was developed for the calibration of longwave-infrared sensors, while allowing for stereo calibration with visible sensors. While developing methods for reconstruction of a plume utilizing visible imagery alone, the intended location for data collects, the Jasper nuclear site in South Carolina, was modeled to scale. This allowed for the deployment of sensors in field to determine the best locations for a 3D reconstruction experiment, as well as providing simulated imagery of condensed water vapor plumes in the visible regime. With this data the methods of Structure from Motion and space carving were implemented to assess the success of reconstruction, and to plan the future experiment at the Jasper site.



Simulated imagery capturing condensed water vapor plumes from mechanical draft cooling towers.

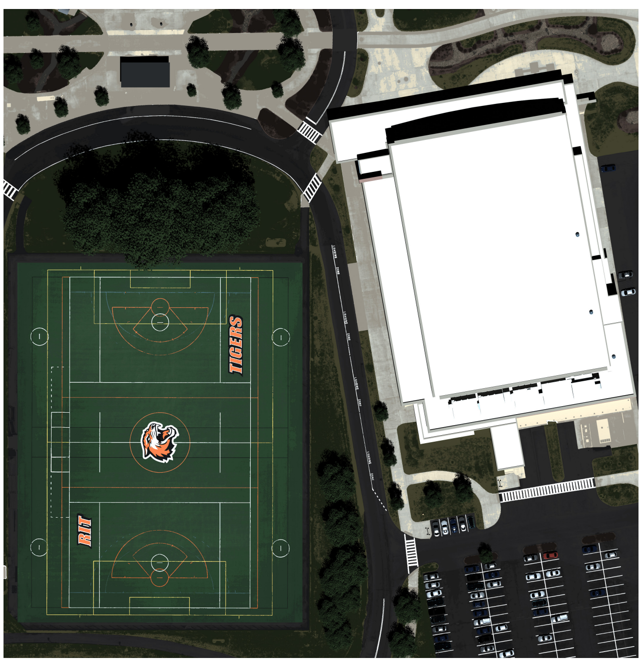
Deep Learning Data Integrity (DIRSIG Scene Development: RIT Bus Loop)

Principal Investigator: Alexander Loui, Carl Salvaggio

Team: Byron Eng, Raymond Chenevey, Morgan Webb, Timothy Bauch, Nina Raqueno, Scott Brown, Ayush Soni, Shubham Patil

Project Description

The Deep Learning Data Integrity project was a collaborative effort involving members from the Department of Computer Engineering, the DIRS lab, and the 3D Digital Design department. Drone-based imagery, ground-based spectral measurements, and 3D geometry of the "bus loop" area on the RIT campus were combined into a new DIRSIG scene.

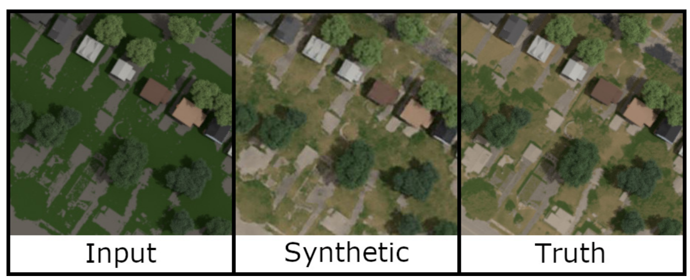


Overview of the RIT Bus Loop scene.

Project Status

Synthetic data generated with the new RIT bus loop scene was used to train and test semantic segmentation algorithms. The efficacy of the semantic segmentation results was evaluated using various levels of fidelity in the simulation to determine if low-quality physics-based simulations, possibly enhanced with the use of generative adversarial networks (GANs) may be able to be used in training deep learning algorithms to perform inference on real data. The RIT Bus loop scene and the accompanying real, multi-modal data offers a unique opportunity with which to perform these studies concerning the use of simulated data in deep learning research and practice.

The RIT Bus Loop scene was designed with high enough spatial resolution to support a variety of low-GSD applications, such as foot traffic. The new scene will be incorporated into the DIRSIG training materials, as it employs



Low fidelity simulated DIRSIG scene enhanced with the use of GANs trained using low-fidelity DIRSIG simulations, high-fidelity DIRSIG simulations, as well as actual collected imagery.

some of the more recently defined "best practices" of scene construction. Ongoing updates and improvements to the scene will be implemented over time including, but not limited to, moving vehicles, new and improved vegetation, and an expansion of the coverage area.

Hyperspectral Video Imaging and Mapping of Littoral Conditions

Principal Investigator: Charles Bachmann

Team: Rehman Eon, Christopher Lapszynski, Gregory Badura

Project Description

The centerpiece of this project is a state-of-the-art integrated mast-mounted hyperspectral imaging system developed by Dr. Bachmann, his students, and RIT staff. The system includes the Headwall visible and near-infrared (VNIR) E-Series micro-Hyperspec High-Efficiency (micro-HE) imager, a General Dynamics maritime-rated high-speed pan-tilt unit, and an onboard Applanix GPS-IMU system for pointing, georeferencing, and precision timestamps. At maximum operating rates, the system can produce a low-rate hyperspectral video imagery time series at about 1.5 Hz. Details of the system and purpose are further described in a recent journal article that was featured on the cover of the Journal of Imaging https://www.mdpi.com/2313-433X/5/1/6. This imaging system has provided the multi-temporal and multi-view imagery that are the primary inputs to radiative transfers models used to retrieve geophysical parameters describing littoral conditions.

Project Status

Using both our hyperspectral mast-mounted system and our hyperspectral goniometer system, the Goniometer of the Rochester Institute of Technology-Two (GRIT-T), the team has developed and validated retrieval algorithms for sediment geophysical properties based on radiative transfer models in both laboratory and field settings. One of our most recent publications uses multi-view and multi-temporal hyperspectral imagery from our mast-mounted hyperspectral imaging system to directly estimate the sediment filling factor (density) (https://doi.org/10.3390/rs12030422). The study described in this article documents a comprehensive field campaign to validate the methodology using multi-view and multi-temporal hyperspectral imagery of a tidal flat on a barrier island. This work builds on an earlier article in which we adapted a radiative transfer model inversion approach that we originally developed and validated in our laboratory using our GRIT-T hyperspectral goniometer system. The extended method allows retrieval of the sediment filling factor from multi-view hyperspectral imagery in field settings. In this earlier article, we used both airborne hyperspectral imagery from the NASA G-LiHT sensor suite as well as multi-spectral satellite imagery from GOES-R. This year, we also submitted a journal article describing the modeling and validation of a methodology to retrieve sediment water content using the DIRS unmanned aerial systems (UAS). This work uses a new radiative transfer model designed specifically to describe sediment pore water (R. S. Eon, C. M. Bachmann, "Mapping Barrier Island Soil Moisture Using a Radiative Transfer Model of Hyperspectral Imagery from an Unmanned Aerial System," submitted to Scientific Reports https://doi.org/10.1038/s41598-021-82783-3). Some of our more recently published laboratory analyses complement our field validation studies and have used our GRIT-T hyperspectral goniometer system to focus on a potentially confounding factor in retrievals of geophysical parameters, namely surface roughness; this article received the prestigious IEEE Geoscience and Remote Sensing Society, 2020 JSTARS Prize Paper Award. In related work, we have also developed a method to quantify the degree of surface roughness from a direct measure of the variability of spectral response with angle. This work also used the GRIT-T hyperspectral goniometer system, which received the 2017 Best Paper Award, Photo-optical Instrumentation and Design, in the Journal of Applied Remote Sensing.

Field validation of models for retrieval of sediment geophysical properties using multi-temporal and multi-view imagery have been the core of our project. Inset photos show (right) the hyperspectral video imaging system deployed on a telescopic mast, (middle) one of the UAS systems with a multi-sensor payload including hyperspectral, LiDAR, thermal, and framing RGB imaging systems as well as ground truth data collection in the field, and (left) our hyperspectral Goniometer of the Rochester Institute of Technology – Two (GRIT-T), which measures the directional dependence of spectral reflectance in both field and laboratory settings.

Improving Estimates of Salt Marsh Resilience and Coastal Blue Carbon

Principal Investigator: Christy Tyler, Charles Bachmann

Team: Rehman Eon, Christopher Lapszynski, Sarah Goldsmith, Avery Miller

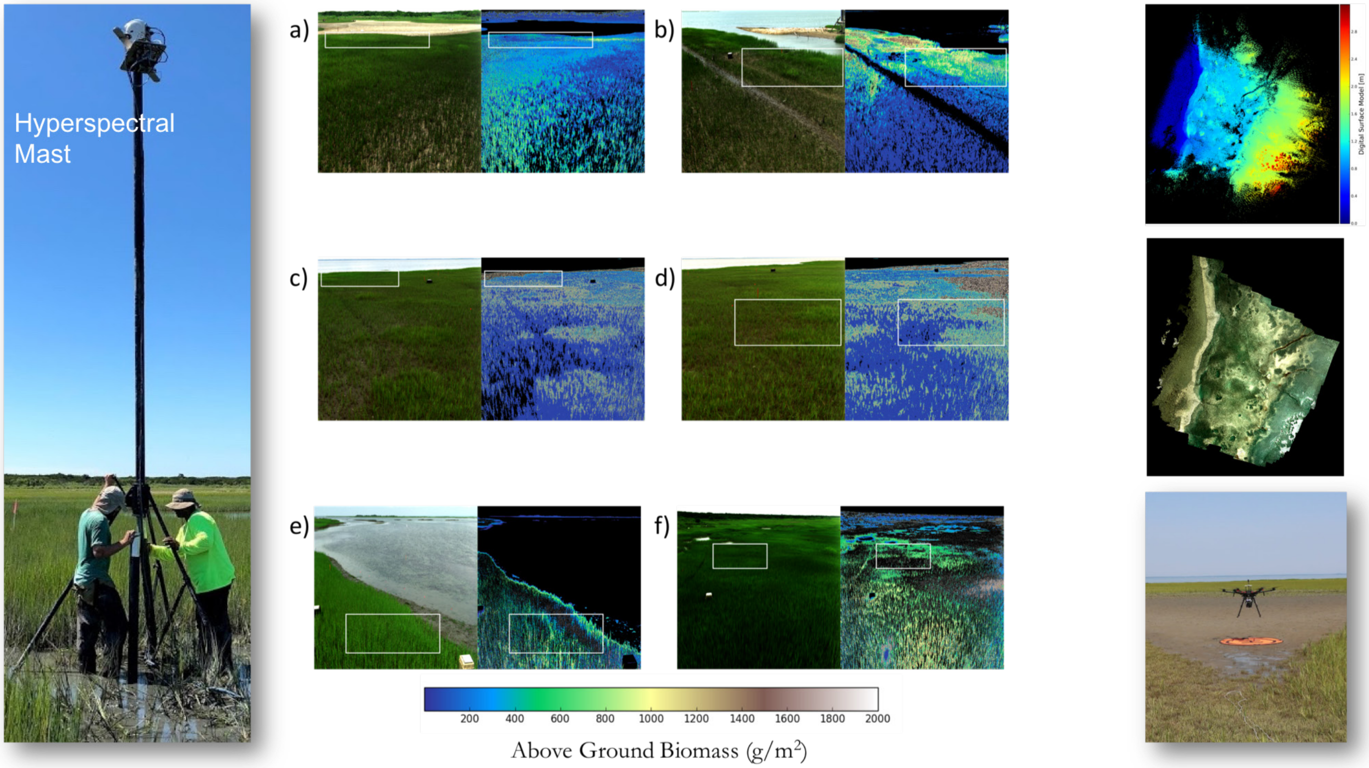
Project Description

This project focuses on the development of more reliable estimates of carbon storage in coastal wetland systems. The goal is to use very high-resolution hyperspectral remote sensing imagery and detailed surface models from LiDAR and stereo RGB imagery in combination with highly detailed contemporaneous biophysical ground truth data to construct more accurate assessments of carbon storage in salt marsh and to scale these results to imaging platforms with lower spatial resolution such as satellites and fixed-wing aircraft. Using the mast-mounted hyperspectral imaging system developed by Dr. Bachmann, his students, and staff, as well as imagery acquired by the MX-1 drone system, Dr. Tyler, Dr. Bachmann, and their students have conducted a number of imaging and ground truth data collection campaigns at the Virginia Coast Reserve (VCR) Long Term Ecological Research (LTER) site. The hyperspectral imagery collected emphasizes these very fine spatial scales which spans from mm-scale to meter-scale spatial resolution. In addition to extensive field data collection and validation, salt marsh specimens have been brought back to RIT and are used with the GRIT-T hyperspectral goniometer in Dr. Bachmann's laboratory to further develop and improve models.

Project Status

Using hyperspectral imagery collected of a marsh chronosequence collected by our team using our mast-mounted hyperspectral system (https://www.mdpi.com/2313-433X/5/1/6) at the VCR LTER site, we have developed models based on the PROSAIL radiative transfer model to retrieve salt marsh biomass at very fine spatial resolution and validated using ground truth data collected on site (Figure 1). These initial results were published in a Special Issue of the journal Remote Sensing (https://doi.org/10.3390/rs11111385) with examples provided in Figure 1 for marshes of varying ages. The site is a perfect laboratory for understanding carbon storage as a function of marsh age because the marsh chronosequence on Hog Island, VA, where the imagery was acquired, consists of marshes ranging in age from 1 to 150+ years. Our most recent publication considers both hyperspectral imagery collected with our hyperspectral mast-mounted system at the VCR LTER as well as laboratory studies with our GRIT-T hyperspectral goniometer data (https://dx.doi.org/10.1117/1.JRS.11.046014). The latter studies of salt marsh vegetation considered various stress conditions (salinity, nutrient load, waterlogging). The goal of the study was to identify spectral predictors of salt marsh stress and to be able to map the condition of marsh systems in hyperspectral imagery to predict relevant measures in the field setting from imagery (foliar nitrogen, chlorophyll, porewater salinity, ORP, etc). Our results from the laboratory study and field validation tests appear in a recent article in Remote Sensing (https://doi.org/10.3390/rs12182938), emphasize of prediction and mapping foliar nitrogen from hyperspectral imagery. Over the course of multiple field campaigns, we have also used the DIRS Lab unmanned aerial systems (UAS) to develop high-resolution models of the surface and canopy from the onboard LiDAR and high-resolution stereo imagery (Figure 1). These data will provide a critical means of extending the validation effort across a much broader spatial scale. In addition, our laboratory analyses, relating vegetation indices such as leaf area index (LAI) to the angular dependence of spectral response using GRIT-T hyperspectral data and three-dimensional canopy models, have been published in the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (https://dx.doi.org/10.1109/JSTARS.2018.2889476).

This study also developed new vegetation indices that take advantage of multi-view hyperspectral reflectance data to provide more robust predictions of vegetation leaf area index. This study took advantage of the joint capability of GRIT-T to measure both a complete hemisphere of reflectance measurements (BRDF) from the onboard spectrometer and a 3-D canopy model using structure-from-motion from an onboard field-of-view camera.



This project is focused on quantitative estimate of "Blue Carbon" storage. Using our mast-mounted hyperspectral imaging system (left), we have developed high-resolution models of salt marsh above-ground biomass (center, showing pairs of hyperspectral scenes and biomass retrievals). We have also used the DIRS Lab UAS systems (bottom, right) to acquire simultaneously hyperspectral imagery (VNIR and SWIR), LiDAR, thermal, and RGB imagery. (Top, right) digital surface model from the UAS LiDAR system, (middle, right) structure-from-motion 3D surface model from the UAS RGB system.

Radiometrically Accurate Spatial Resolution Enhancement of Spectral Imagery for Improved Exploitation

Principal Investigator: David Messinger

Team: Sihan Huang, Rey Ducay, Joe Carrock

This research project seeks to address the challenging problem of sharpening remotely sensed hyperspectral imagery with higher resolution multispectral or panchromatic imagery, with a focus on maintaining the radiometric accuracy of the resulting sharpened imagery. Traditional spectral sharpening methods focus on producing results with visually accurate color reproduction, without regard for overall radiometric accuracy. This is done primarily to support exploitation through visual interpretation. However, hyperspectral imagery (HSI) is not exploited through purely visual means. Instead, HSI is processed through (semi-) automated workflows to produce various resulting products. Tasks of interest include material classification and identification, anomaly detection, and target detection. For many of these applications, individual pixel spectra are compared against either other in-scene spectral signatures, or library signatures. Consequently, maintaining radiometric accuracy is a key goal of spatial resolution enhancement of hyperspectral imagery. Here, our focus will be in characterizing the issues related to accurate sharpening, and in particular understanding how the scene spatial - spectral content and complexity impact the ability to sharpen a particular image, or portion of an image.

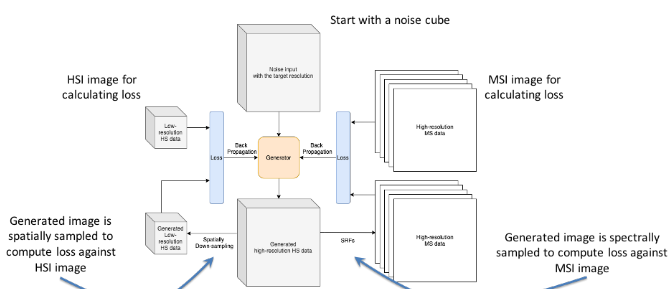


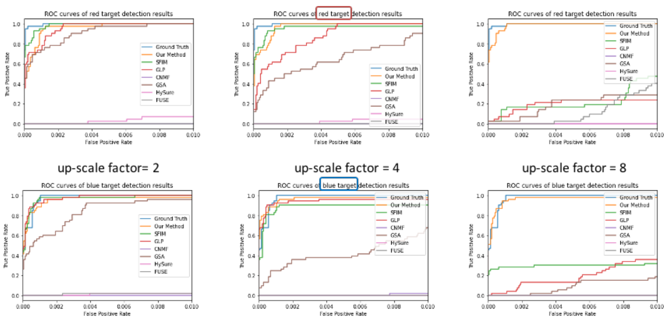
Figure 1 Learning framework developed for fusion of high spatial resolution MSI with low spatial resolution HSI. Note how two loss functions are used to ensure both spatial and spectral accuracy.

This project has three main tasks. The first task seeks to understand the current state of the art, as well as the impacts of various scene contents on the accuracy of different sharpening approaches. "Traditional" panchromatic sharpening algorithms generally focus on improving the color improvement of multispectral images and are typically assessed as such with image-wide metrics of spectral similarity and error. However, significant errors in individual pixels may occur which will have a strong impact on applications such as target detection. Our goal here is to understand how traditional algorithms will perform when applied to hyperspectral imagery, and assessed against the application of target detection.

Sharpening algorithms were tested against two hyperspectral images. The data were collected with the SpecTIR Propec-TIR hyperspectral sensor and cover the spectral range from 400 - 2500 nm with approximately 5 nm spectral resolution. The spatial resolution is 1m. The agricultural scene contains a field with over 100 targets of known material and location, while the urban scene was a collection of opportunity with little ground truth. However the two scenes provide an interesting challenge due to the dramatically differing scene content. The scenes were downsampled by a factor of 4 relative to the original data. Per-pixel spectral comparisons show sometimes good agreement between the sharpened image and the original, however, there are also many instances of significant variation. This is true in both scenes, and in general happens on edges or in relatively "dark" areas of the scene. None of the algorithms tested consistently produce high quality spectral signatures in the sharpened imagery.

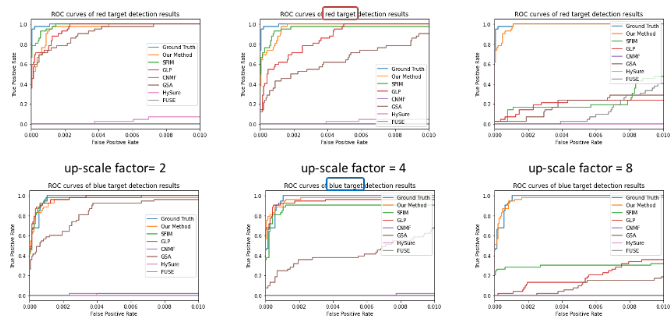
The second task considers the problem of developing a new approach to sharpening Vis-NIR hyperspectral imagery with high resolution multispectral imagery. A novel learning framework was developed to approach the problem. The philosophy is that we know the high spatial resolution, low spectral resolution answer, we know the low spatial resolution, high spectral resolution answer, and we need to learn the fusion of them while maintaining radiometric accuracy. The key to this approach is in application of loss functions that consider both known answers. However, we leverage the requirement on the algorithm that we can not require the method to have labeled data for the training process. The framework can be seen in Figure. ROC curve results, from application of the ACE target detector against felt targets in the scene, are shown in Figure 2. These results demonstrate that the new algorithm consistently provides radiometrically accurate sharpening products and can be used successfully with a target detection algorithm.

Finally, a third task planned and executed an experiment campaign using the RIT UAV hyperspectral imaging system to collected data at multiple altitudes. This alleviates the need to simulate data and will provide the opportunity for quantitative assessments of novel algorithms developed under this program. A ground photo of the target layout is shown in Figure 3. These images will be used in future years of this project.



30

Figure 2 Ground photo of the target scene used to collect hyperspectral imagery over targets of various size and material at multiple altitudes.



30

Figure 3 ROC curves for the red (top) and blue (bottom) felt targets for various spatial scale differences in the agricultural scene. (left) 2x, (middle) 4x, (right) 8x.

Assessing the in-flight Performance of the Multi-Band Uncooled Radiometric Imager (MURI)

Principal Investigator: Aaron Gerace

Team: Eon Rehman, Nina Raqueno, Tania Kleynhans

Project Description

The sponsor developed and flight-tested a six-band thermal sensor to demonstrate its potential utility as a low-cost spacebourne instrument for future Landsat missions. RIT conducted several modeling efforts to drive the radiometric design of the sensor and conducted a ground campaign to provide reference measurements to support test flights conducted in 2019 over the Los Angeles area.

Project Status

Two campaigns were conducted in 2019 to demonstrate the fidelity of the MURI six-band thermal instrument. As shown in Figure 1, MURI image data show good agreement with (forward-modeled) reference measurements obtained over water targets. Note that the mean temperature difference between observed and reference for these data is 0.18 [C] with a standard deviation of 0.57 [C] which is comparable to the fidelity of Landsat's Thermal InfraRed Sensor (TIRS). Figure 2 shows image data collected with the six-band MURI instrument over El-Derado Park in Los Angeles, California. A five-band temperature/emissivity separation was performed over four materials to assess MURI's potential to be used to derive emissivity. The retrieved emissivities are in good agreement with data obtained from an emissivity library for the corresponding materials.

A third campaign is scheduled for October 2020. The sponsor will lead the airborne campaign with their improved MURI instrument that contains arrays with higher sensitivity. RIT will again lead a ground campaign to acquire reference temperature and emissivity measurements. An assessment of MURI-observed vs. reference measurements will be conducted to determine the potential improvements of the new instrument on image fidelity.

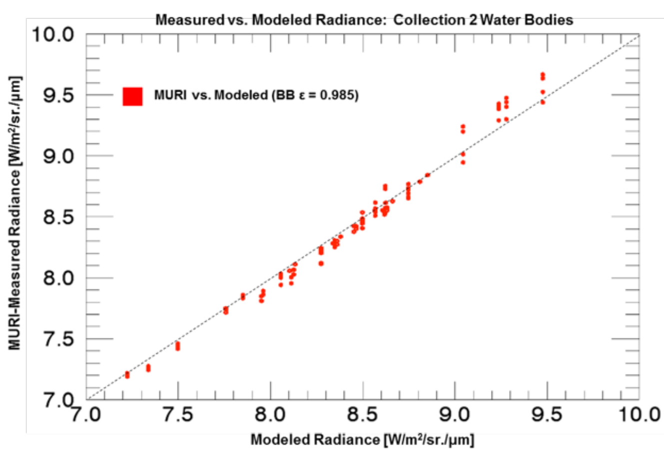


Figure 1. Comparison of MURI-measured vs. (forward-modeled) reference radiance measurements acquired during a 2019 campaign over the Los Angeles, California area. Note that the mean temperature difference between observed and reference for these data is 0.18 [C] with a standard deviation of 0.57 [C] which is comparable to the fidelity of Landsat's TIRS

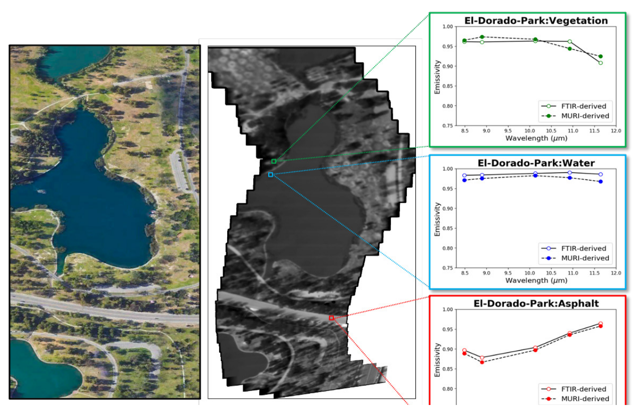


Figure 2. Image data collected with the six-band MURI instrument over El-Derado Park in Los Angeles, California. A five-band temperature/emissivity separation was performed with the image data for four materials. The resulting emissivities are in good agreement with library data.

Calibration & Validation of Landsat Thermal Sensors and their Higher Level Surface Temperature Products

Principal Investigator: Aaron Gerace

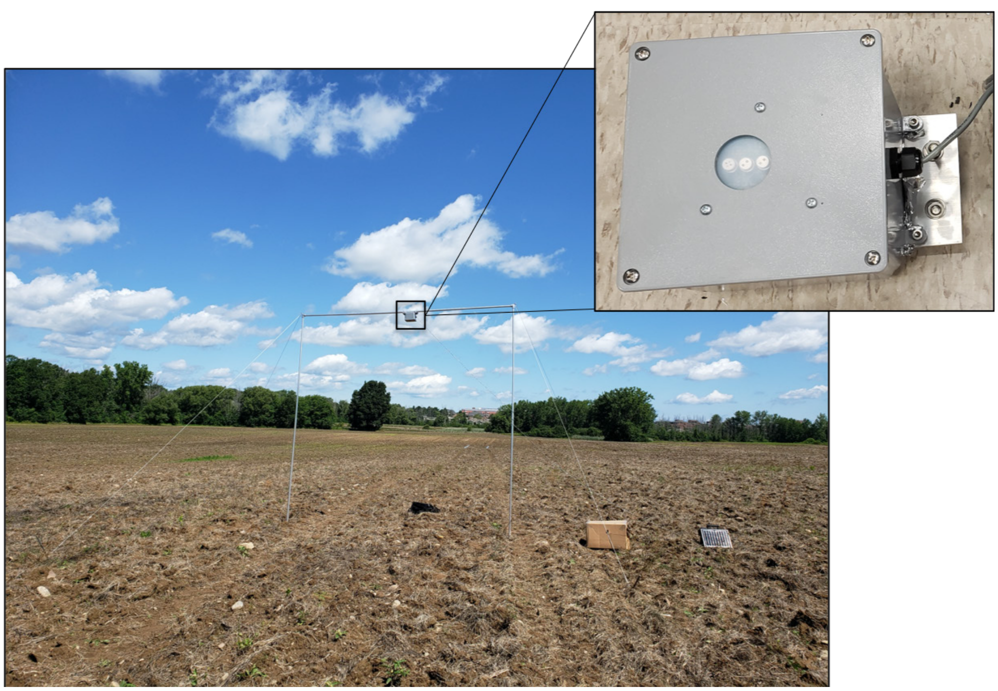
Team: Eon Rehman, Robert Kremens, Benjamin Kleynhans, Matthew Montanaro, Nina Raqueno, Lucy Falcon

Project Description

The Rochester Institute of Technology (RIT) has a long history of supporting calibration efforts for Landsat's thermal space-borne sensors. Recently, the sponsor has started releasing higher-level products to users to facilitate research efforts. To support the verification of their Land-Surface Temperature product, RIT is developing a ground-based network of thermal radiometers that will be placed across the continental US to obtain reference measurements. It is anticipated that this network will not only provide a much-needed source of data to enhance verification efforts but also improve our understanding of the Earth's surface.

Project Status

Leveraging lessons-learned from previous efforts, an eight-band thermal radiometer has been developed to measure temperature and emissivity in the longwave region of the electromagnetic spectrum. Preliminary field campaigns have begun to identify potential issues with the sensor and modifications will be made (as needed) to enable the instrumentation to be placed permanently in the field. A cellular capability is being included in the final design to enable the transmission of data to a web server so the data can be made available to potential science users. It is anticipated that six radiometers will be placed in the field by the end of the calendar year (2020).



Satellite-derived Land Surface Temperature (LST) Split Window Algorithm Development and Validation

Principal Investigator: Aaron Gerace

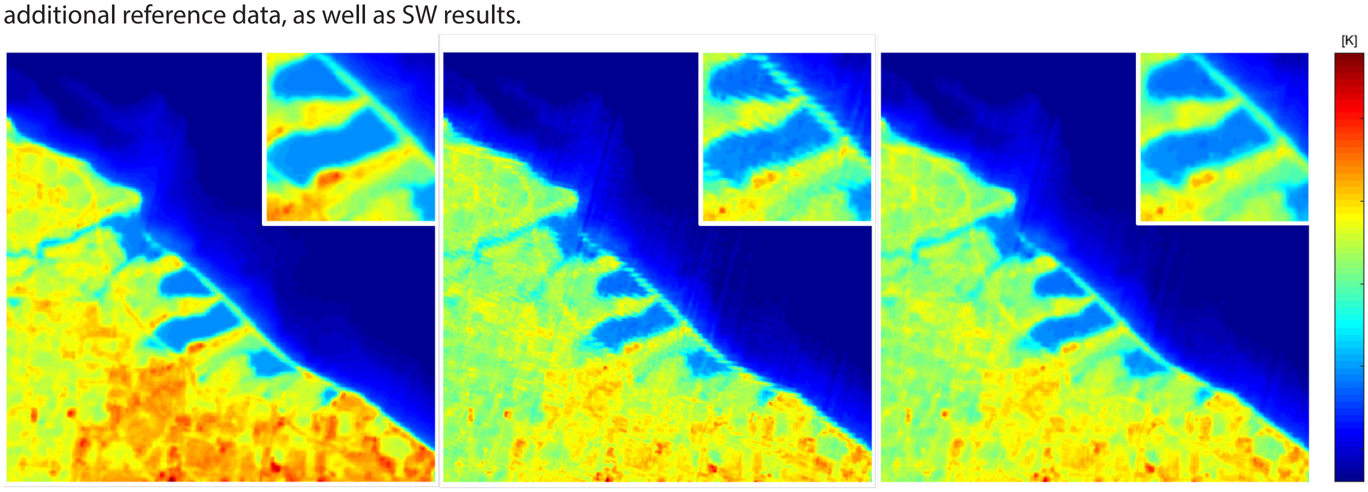
Team: Tania Kleynhans

Project Description

Several Split Window (SW) algorithms have been successfully applied to infrared satellite data (e.g. MODIS, VIIRS) for the estimation of land surface temperature. This research focuses on creating a Split Window algorithm for the Thermal Infrared Sensor (TIRS) onboard Landsat 8. Results are compared to the current Single Channel surface temperature method and in-situ validation sites. These sites include the SURFRAD network as well as ocean buoy measurements (NOAA) and Lake Tahoe and Salton Sea buoys (JPL). Results of this study are provided to the sponsor to support their goals of releasing a validated land-surface temperature product to users.

Project Status

In preliminary studies, the SW LST performed slightly better than the SC method to estimate LST using a combination of SurfRad validation sites and buoys as ground reference points. Changes to the SW algorithm to compensate for aliasing appearing when difference terms are calculated, has been added and is described in the Remote Sensing article Towards an Operational Split Window-Derived Surface Temperature Product for the Thermal Infrared Sensors Onboard Landsat 8 & 9. A SW uncertainty product has been developed to inform users of the accuracy of the SW LST data. The SC method will be released in collection 2, and studies are underway to validate final results before release. This involves comparisons with additional reference data, as well as SW results.



Comparison of surface temperature products: Single channel product (left), the nominal split window product (middle), and the proposed split window product (right) (Landsat scene ID:LC08_L1TP_016030_20190413_20190422_01_T1).

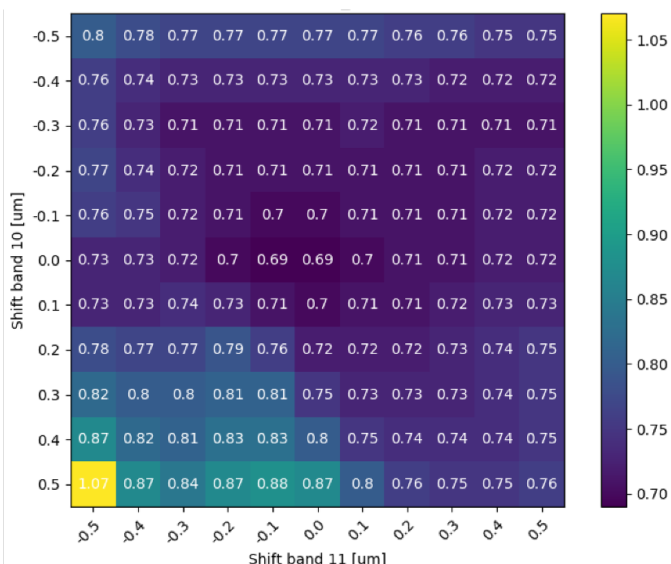
Simulation and Modeling to Support Definition of Sustainable Land Imaging (SLI) System Requirements

Principal Investigator: Aaron Gerace

Team: Rehman Eon, Tania Kleynhans, Matthew Montanaro

Project Description

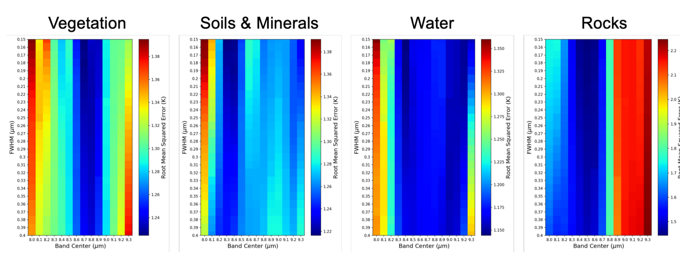
The Sustainable Land Imaging (SLI) program is committed to extend the nearly fifty-year data record of space-borne measurements of the Earth's surface collected from Landsat's reflective and thermal instruments. Through the development of a system of space-borne sensors, and perhaps the inclusion of alternative data sources, the SLI program is interested in identifying cost-effective solutions to acquiring consistent and continuous data to support science applications related to the monitoring of Earth's natural resources. To support these interests, RIT is performing simulated trade studies that investigate the impact of potential system requirements on various science applications.



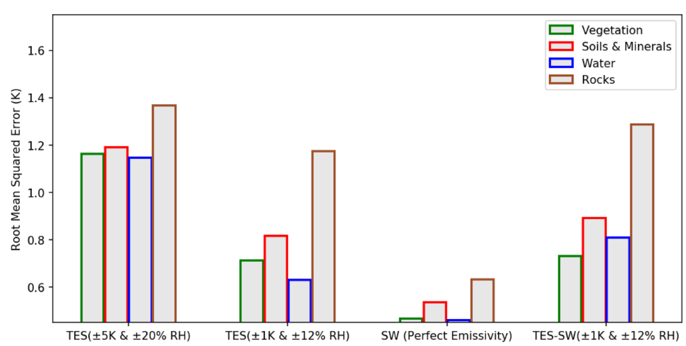
Comparing the temperature RMSE for the TES, SW and TES-SW hybrid algorithm for 5-band imaging system.

Project Status

This project aims to support the definition of requirements for future Landsat thermal instruments in retrieving accurate land-surface temperature, which represents a key input parameter to several science applications (e.g., estimation of evapotranspiration, drought monitoring). As such, RIT conducted simulated studies to identify the optimal number, shape and placement of Long Wavelength Infrared (LWIR) bands, which will help minimize errors in the surface temperature retrieval process. In these studies, RIT looked at the performance of two temperature retrieval algorithms in determining requirements for future Landsat thermal instruments; (1) split-window and (2) temperature/emissivity separation. We also developed a TES-driven SW algorithm to assess the potential for improving surface temperature estimations using a hybrid approach.



The RMSE in the retrieved temperature using the TES algorithm for the optimal third band when the two bands are the nominal Landsat TIRS bands for the four material classes.



The root-mean squared error (RMSE) in the retrieved temperature from the split window algorithm by shifting of the nominal Landsat TIRS bands.

Thermal Image Systems Engineering Support

Principal Investigator: Matthew Montanaro

Team: Tania Kleynhans

Project Description

This project provides general calibration and systems support for the Landsat thermal band instruments for NASA. Specifically, this involves the continuing on-orbit characterization and calibration of the Landsat 8 / Thermal Infrared Sensor (TIRS) instrument and the pre-flight calibration of the TIRS-2 instrument for the upcoming Landsat 9 mission (scheduled for launch in 2021). The PI serves as the Deputy Calibration Lead for the TIRS-2 project and is a member of the Calibration and Validation team for the Landsat program. Team members also provide technical expertise and guidance on Landsat thermal image products to the Landsat Science team and USGS.

Project Status

Over the past year, the PI has been involved in the pre-flight environmental tests for the TIRS-2 instrument at the NASA Goddard Space Flight Center by writing test procedures, coordinating calibration activities with other systems leads, executing calibration data collection procedures, processing and analyzing image characterization datasets, writing requirement verification reports, and presenting results to project management. These efforts led to the successful on-time delivery of the instrument to the Northrup Grumman facility where the Landsat 9 observatory is being constructed. Calibration results from these pre-flight tests have been delivered to the US Geological Survey for implementation into the Landsat ground processing system that will process and distribute Landsat image data to users. Additionally, major progress was made over the past year supporting new land surface temperature products for the Landsat program through the refinement of the split window temperature product to be made available soon for select users. Preliminary discussions have also began on architecture studies regarding the next generation Landsat thermal systems.

L'Ralph Instrument Calibration Support

Principal Investigator: Matthew Montanaro

Project Description

This project provides support for the calibration and validation of the Lucy/Ralph instrument for NASA. The instrument is a visible/NIR multispectral and a short wave IR hyperspectral imager designed for rocky material identification for NASA's Lucy mission to visit multiple Jupiter Trojan asteroids (scheduled for launch in 2021). The PI is involved in developing calibration test procedures and executing calibration characterization tests during pre-flight instrument checkout at NASA Goddard Space Flight Center. These efforts are to support the spectral, geometric, and radiometric characterization of the instrument to ensure the primary and secondary science objections of the Lucy mission are met. The PI interfaces with the instrument engineering team, calibration team, and mission science team to convey instrument performance characteristics that may influence science results.

Project Status

The past six months have been focused on developing the test narratives for pre-flight testing at NASA Goddard and supporting test equipment setup. Recently the instrument completed the first round of spectral characterization testing in which meaningful image data was acquired by the instrument for the first time. The PI assisted in the execution of this test and in the subsequent data processing. This work will continue for the upcoming environmental tests to ensure a speedy delivery of the instrument to the spacecraft manufacturer.

Advanced Hyperspectral Exploitation Using 3D Spatial Information

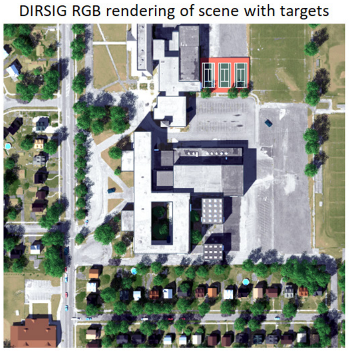
Principal Investigator: Emmett Ientilucci

Team: Michael Gartley

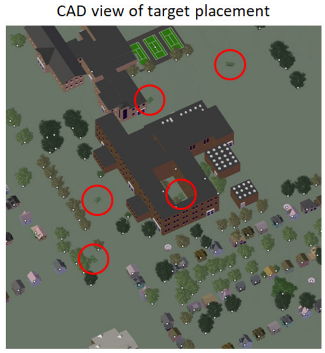
Project Description

There is a need to advance hyperspectral exploitation algorithms by incorporating 3D spatial information for improved target detection and identification. Hyperspectral imaging (HSI) has demonstrated utility for material classification and target detection. Using HSI alone can produce false alarms and possible low confidence in detects for certain target classes. Additional 3D information can be used to help improve the separability of material and target classes, which can, ultimately, reduce the number of false alarms. The overall focus of the effort is to improve and expand upon previous work with emphasis on target detection, rather than material classification.

DIRSIG RGB rendering of scene with targets



CAD view of target placement



Example DIRSIG RGB rendering (left) an CAD view (right) of Megascene1 with T-72 tank targets placed in the open, along a tree-line, within an urban canyon, and next to a building site.

Project Status

RIT is working to choose target shapes and spectra of interest to the sponsor to be placed throughout DIRSIG Megascene1. Many instances of the target of interest are placed within the scene in locations ranging from wide open to the sun with minimal adjacent surfaces to hidden within a building courtyard and within the shadow of a treeline. Emphasis is placed on radiometric accuracy of the DIRSIG simulations and include radiometric effects of adjacent surfaces, partial transmission through tree leaves, and a MODTRAN derived skydome. Additionally, confuser targets are also being placed around the scene with similar spectra and 3D shape in order to test the robustness of detection algorithms. Simulations will also be run for a variety of sun angles. Pixel geo-location truth (East-North-Up x,y,z coordinates) for each pixel will be provided to the sponsor for use in the detection algorithm.

Analysis of NOx Blast Fumes with Drones

Principal Investigator: Emmett Ientilucci

Team: Bob Kremens, Nina Raqueno, Tim Bauch, Nelmy Robles-Serrano

Project Description

A private company who manufactures, distributes, and applies industrial explosives for industries including quarrying, mining, construction, and other applications. Although it's unusual, these massive explosions can release a foreboding yellowish-orange cloud that is often an indicator of nitrogen oxides—commonly abbreviated NOx. The company is seeking research into the ability to image these plumes so as to potentially estimate volume and concentration. The ultimate goal would be to image these plumes in the field with multiple drones.

Project Description

We have explored the usage of structure from motion to image 3D objects, run experiments to estimate volume of 3D solid objects, explored the usage of multiple cameras to capture images of still objects. We are currently working on utilization of a GPS mechanism for camera triggering along with video frame extraction towards modeling actual plumes. We are utilizing smoke grenades as surrogate for spatial imaging.

Shown is a yellowish-orange NOx cloud released, on rare occasions, by quarry and mine blasts.

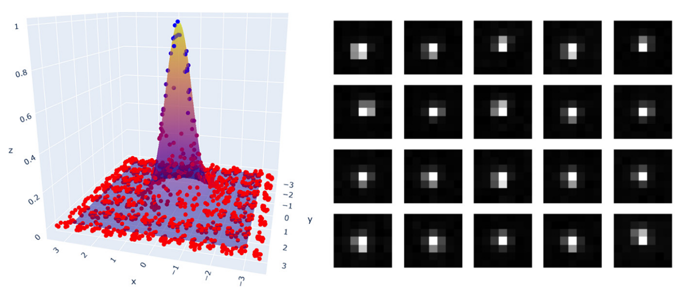
Satellite Calibration with Flare

Principal Investigator: Emmett Ientilucci

Team: David Conran

Project Description

FLARE is a new capability for performing the vicarious radiometric calibration of high, medium, and low spatial resolution sensors. The SPecular Array Radiometric Calibration (SPARC) method employs convex mirrors to create two arrays of calibration targets for deriving absolute calibration coefficients of Earth remote sensing systems in the solar reflective spectrum. The first is an array of single mirrors used to oversample the sensor's point spread function (PSF) providing necessary spatial quality information needed to perform the radiometric calibration of a sensor when viewing small targets. The second is a set of panels consisting of multiple mirrors designed to stimulate detector response with known at-sensor irradiance traceable to the exo-atmospheric solar spectral constant. The combination of these arrays with a targeting station is the basis for a new, on-demand commercial calibration network called FLARE.



On the (left) is the constructed oversampled system PSF from a collection of 20 images on the (right). The system PSF is modeled against a 2D Gaussian distribution with a RMSE of approximately 1.4%. Due to the discrete detector elements, the optical PSF is naturally undersampled and phasing can be observed in the 7x7 sub-images on the (left). The phasing of the system PSF makes the reconstruction possible and retrieves the majority of the aliased information. Further processing of the oversampled system PSF will result in a 2D MTF of the imaging system.

Project Description

We are currently working with the sponsor writing algorithms, as well as processing data, for the generation of PSF's and MTF's on imagery from the FLARE network.

The image on the (left) is a collection of 7 mirrors used in a drone experiment to determine the spatial extent of the system PSF. The MicaSense blue channel image of the mirrors can be seen on the (right). The collection of mirrors contained within the Ground Sampling Distance (~7cm) of the MicaSense produces an undersampled version of the system PSF and requires multiple images to construct a well-defined system PSF for this channel.

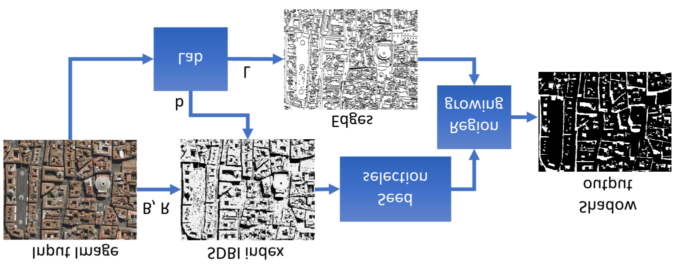
Shadow Detection

Principal Investigator: Emmett Ientilucci

Team: Prasanna Reddy Pulakurthi

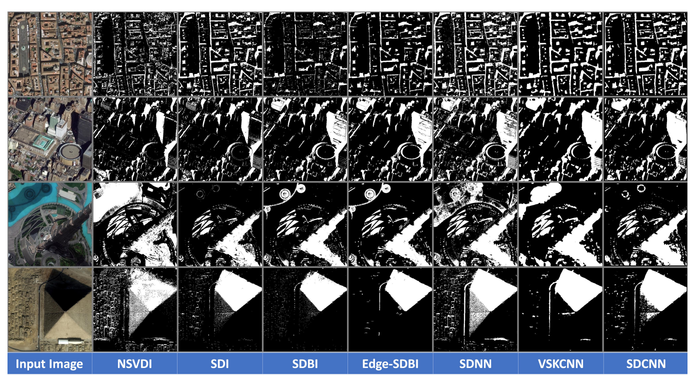
Project Description

Shadows are present in a wide range of aerial images from forested scenes to urban environments. The presence of shadows degrades the performance of computer vision algorithms in a diverse set of applications. Therefore, detection and mitigation of shadows is of paramount importance and can significantly improve the performance of computer vision algorithms. Although there are several existing approaches to shadow detection in aerial images, correctly detecting shadows in the vegetation and water areas is still a challenge in some cases.



Flow chart for the Edge-SDBI index algorithm utilizing a WV2 input image.

In this research, we developed five new approaches to shadow detection in aerial imagery. This includes two new chromaticity based methods (i.e., Shadow Detection using Blue Illumination (SDBI) and Edge-based Shadow Detection using Blue Illumination (Edge-SDBI)) and three machine learning methods consisting of a neural network (i.e., Shadow Detect Neural Network (SDNN)), and two convolutional neural networks (i.e., Variable Sized Kernels Convolutional Neural Network (VSKCNN) and the Shadow Detect Convolutional Neural Network (SDCNN)). The SDBI index is specially designed to accurately classify shadow pixels from vegetation. These algorithms are tested on four different aerial imagery data sets. Results are assessed using both qualitative (visual shadow masks) and quantitative techniques. Conclusions touch upon the various trades between these approaches, including speed, training, and accuracy. This research has been submitted for publication to IEEE Transactions on Geoscience and Remote Sensing (TGARS).



Shadow mask output for all the algorithms on the WV2 data.

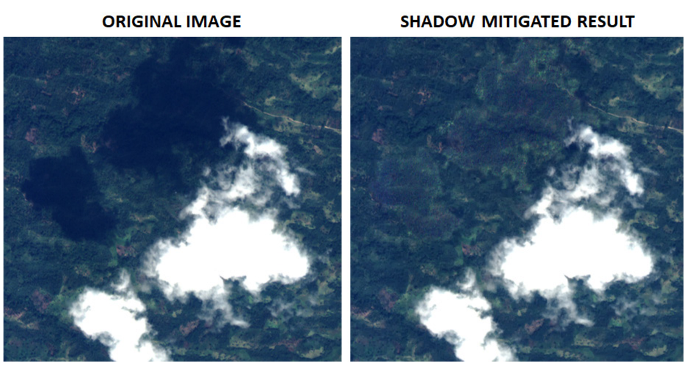
Shadow Mitigation

Principal Investigator: Emmett Ientilucci

Team: Michael Gartley, Scott Couwenhoven

Project Description

Shadows are present in a wide range of aerial images from forested scenes to urban environments. The presence of shadows degrades the performance of computer vision algorithms in a diverse set of applications, for example. Therefore, detection and mitigation of shadows is of paramount importance and can significantly improve the performance of computer vision algorithms. This work assumes as input a multispectral image and co-registered cloud shadow map which are used to calculate shadowed pixel spectral statistics and adjusting to match the statistics of spectrally similar sunlit pixels resulting in a shadow mitigated multispectral image.



Orbview-3 RGB image chips showing original (left) and final result (left) after shadow mitigation algorithm is applied.

Project Status

RIT is developing a shadow mitigation algorithm which focuses on removing the appearance of shadows in high spatial resolution multispectral overhead collected imagery. The intent is for material spectral appearance to be constant regardless of the level of sun-light and shadow for use in sponsor algorithms. Our approach utilizes multispectral image data and a binary cloud shadow map as input and outputs a multispectral image with shadows removed. The removal of shadows is accomplished by determining spectral statistics of shadowed materials, comparing to spectral statistics of spectrally similar sunlit material surfaces and adjusting the shadowed pixels to match the brightness of the sunlit pixels. We have found good shadow mitigation results for small (512x512 pixels) image chips and less than optimal results for larger scene extents. We are currently researching methods for processing statistics on a cloud by cloud basis to extend the acceptable image chip performance to an acceptable full scene performance.

Unmanned Aerial System Data Collections

Principal Investigator: Emmett Ientilucci

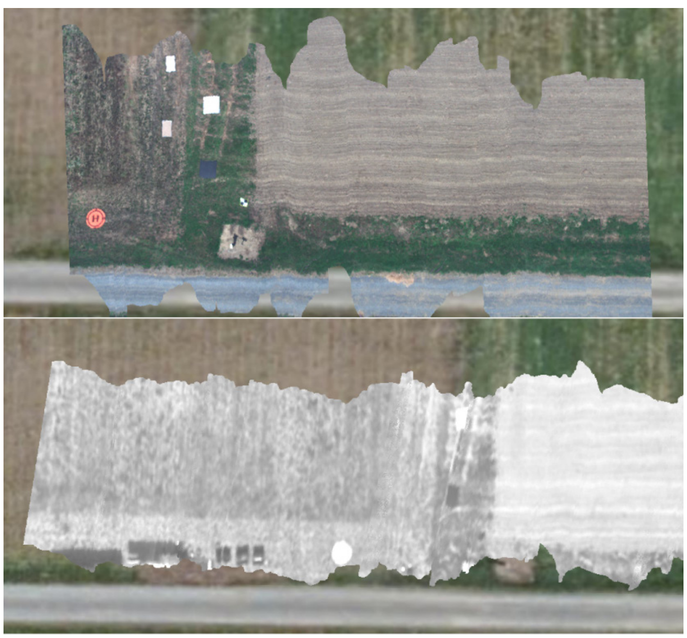
Team: Nina Raqueno, Tim Bauch

Project Description

RIT has been working work the sponsor to provide them with a variety of data sets with heavy focus on varying sensor modality, number of spectral bands (i.e., multi- and hyper-spectral), and imaging scenarios.

Project Status

We have been collecting and processing data related to a variety of scenarios that can be used for input to various algorithms. Recently, this includes shadowed targets, glint confuser, and soil moisture data using RGB, VNIR hyperspectral, SWIR, thermal, as well as LiDAR sensors.



RGB composite (bands 480, 549, 659 nm) and (bottom) SWIR band 2201 nm (dry areas are bright) of farm field showing a newly planted bean field (right side) is dry bare earth in contrast to the moister vegetated areas.

(top) Mosaic from the 5 band Micasense camera over our new Tait Preserve test area illustrating shadowing experiments and (bottom) a single image frame from an oblique RGB mission showing many sources of confusors (e.g., water glint, direct sun reflection, and cloud reflection).

Registration of Full Motion Video

Principal Investigator: Emmett Ientilucci

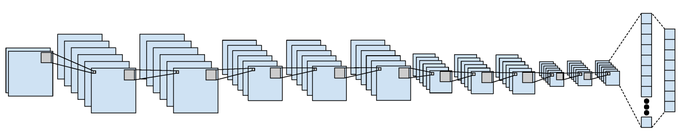
Team: Liam Smith, Nina Raqueno

Project Description

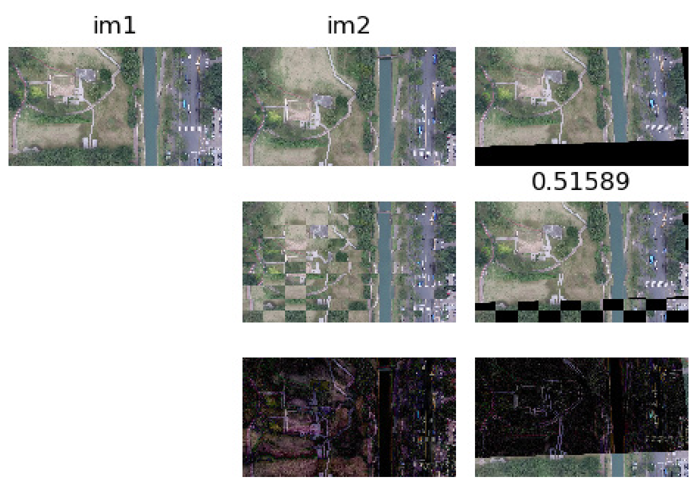
In many cases, it is important to have location information associated with imagery. When position and pointing telemetry is provided by the imaging platform, it is trivial to compute this information. However, when this information, which includes GPS, is deficient, the missing location information must be extrapolated. Thus there becomes a need to extract location information from motion imagery in such a scenario. Various techniques exist to compensate for lack of GPS data in an aerial image matching context, including using additional information from other sensors. Our work focuses on how various machine learning techniques can be implemented and leveraged to perform image matching, or alignment, in a real-time.

Project Status

Our investigations of feed-forward convolutional neural networks (to perform image alignment) has resulted in three approaches, called HNET, VWNET and MOFLNET. HNET is based on literature, with a feed-forward convolutional neural network (CNN) that takes stacked grayscale images to produce a homography. VWNET is a modification of HNET that instead produces a coarse vector field describing the warping between two images. MOFLNET is another modification of HNET, essentially appending the CNN with a set of transposed convolutions that produce a stacked grayscale image pair representing the optical flow between the two input images, which has similarities to models in literature.



Visualization of the HNET architecture, which is based on the model presented in (D. DeTone, et. al., CoRR,2016).



Example comparison image set to show that HNET performance is good on unseen and unrelated data. Img1 is the reference image while img2 is the warped image. The weighted average loss metric is shown below the result (upper left). Values between 0.5 and 0.59 are good while values below 0.49 are very good. We also visualize the alignment by taking the reference and warped images and overlaying them in a grid / checkerboard pattern so that alignment of features can be easily evaluated (second row). The absolute difference is shown (bottom row).

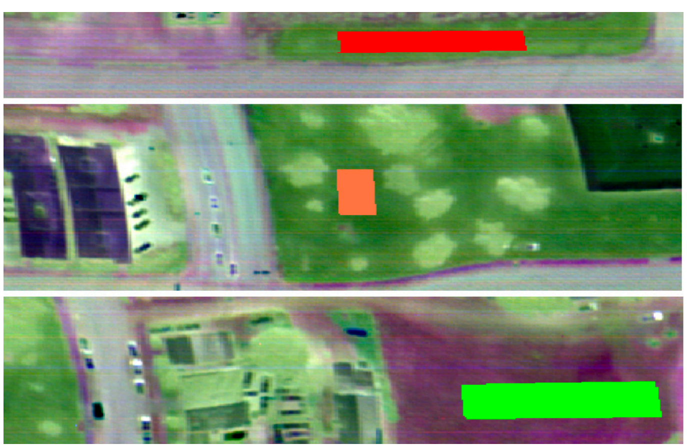
Integrating TES and Modern Target Detection Capability into the FASSP Model

Prinicpal Investigator: Emmett Ientilucci

Team: Runchen Zhao

Project Description

A material's surface emissivity can be affected by many things including particle size, for example. Increasing or decreasing the particle size can vary the dominant scattering sources between surface scattering and volume scattering. Thus, how the particle size, e.g., a powder, impacts target detection performance is a valuable question, especially in the LWIR domain. To analyze this, parameter trade-off studies focusing on particle size can be studied using Forecasting and Analysis of Spectroradiometric System Performance (FASSP) model. FASSP is an end-to-end system performance forecasting analysis tool which uses first and second order statistics associated with targets and background. The current FASSP model does not have a temperature/emissivity separation (TES) algorithm which is needed to perform realistic analysis in the LWIR. In addition, a state-of-the-art and widely used detection algorithm called adaptive cosine estimator (ACE) is to be implemented. Due to the nature of FASSP (i.e., propagating statistics), ACE cannot be directly coded into the model. An alternative and equivalent algorithm called the cotangent detector will be utilized instead.



AHI LWIR data taken near the Yuma Proving ground in Yuma, AZ. False color images were generated using band 20 (8 um), band 96 (9.3 um) and band 176 (10.7 um). Shown are regions of interest (ROI) illustrated as a green region (4455 pixels), an orange region (2432 pixels) and a red region (1610 pixels). The overall mean and covariance were computed from these regions.

Project Status

We have already finished the development of a statistical TES algorithm (called S-ISSTES) and implemented it into FASSP as well as a cotangent detector which is equivalent to ACE. Comprehensive validations addressing both performance of S-ISSTES and the newly improved FASSP have been completed. Two real HSI datasets, HyTES and AHI, combined with simulated data were used in the validations. These results are to be assembled into two journal papers. Findings for the S-ISSTES algorithm are to be submitted to IEEE Geoscience and Remote Sensing Letters.

The HyTES data was captured from the Gallo Colony Vineyards in California. Regions of interest (ROI) were carefully selected (i.e., considering region uniformity and avoiding image artifacts) at different locations in the data. Mean spectrum of target and background used in our validation studies. The target spectrum mean was calculated from the green regions while the background mean spectrum was calculated from all five red regions.

Transforming the Table Beet Industry in NY through Precision Agriculture – Estimating Beet Yield using UAS Sensing

Principal Investigator: Jan van Aardt, Sarah Pethybridge

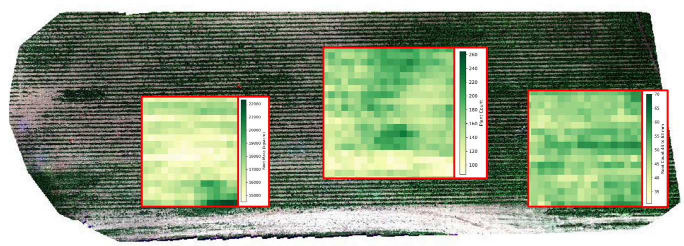
Team: Sarah Pethybridge, Rob Chancia

Project Description

The Rochester area is home to a growing economy of table beet root growers and production facilities for various organic beet products, headed by Love Beets USA. Since 2018, Love Beets has been working with the RIT DIRS group and Cornell AgriTech to explore the application of UAS remote sensing imagery for yield, plant count, and root size distribution forecasting. Beginning in the spring semester 2020, Rob Chancia (MS student) began developing machine learning models with spectral inputs derived from the UAS imagery observed during the 2018 and 2019 growing seasons. Having data from two seasons allows us to develop and vet more generalized models of the agronomic yield parameters. We can then confidently extend our models beyond the particular modular ground truth plots used in a single season of our study and forecast an entire field, or even imagery of fields in future seasons. Figure 1 shows imagery of a beet root field with multiple patches overlain, containing square meter grids of preliminary modeled yield parameters for those sections of the field (root mass as kg/acre, plant count, and roots in an optimal diameter range).

Project Status

This work is well on its way to addressing the goal of developing an operational software package including models, algorithms, and methods which output easily interpretable yield maps for farmers and growers. A journal article and code repository are in preparation.



An example of different aggregated field/crop products, derived from the underlaying UAS image.

In the fall Rob will begin work on a new project to assess grapevine nutrients using spectral and structural data derived from UAS imagery. We will build off of previous work done at RIT, including by Grant Anderson (RIT-CIS 2016) and Uday Kant Jha (RIT-MATH 2017) who used data obtained with a handheld hyperspectral radiometer to determine correlations between significant spectral bands and ground truth N, K, P, Mg, Zn, and B nutrients in grapevines. Work by Ronaldo Izzo (RIT-CIS 2019) also applies in this context - Ronnie used UAS imagery of vineyards to assess grapevine moisture stress. The new project similarly seeks to exploit non-destructive UAS remote sensing data and machine learning to provide near-real-time interpretable maps of nutrient status, that growers can use to make actionable management decisions throughout the growing season. The first UAS observation is occurred in August and September of 2020 near Lake Erie, in Collaboration with Dr. Terry Bates (Cornell University). We are also planning UAS flights for 2021, centered around the bloom and veraison growth stages, again at the Lake Erie site, and also at vineyards near Ithaca, NY (Dr. Justine vanden Heuvel; Cornell University).

Fostering Agriculture Remote Sensing (FARMS) Alliance

Principal Investigator: Jan van Aardt

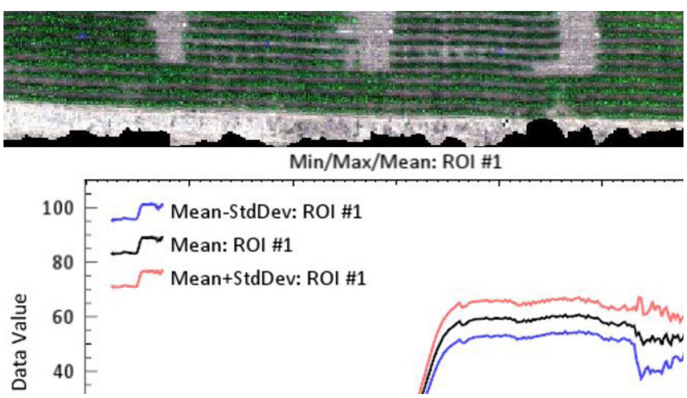
Team: Carl Savaggio, Sarah Pethybridge, Amir Hassanzadeh, Fei Zhang

Project Description

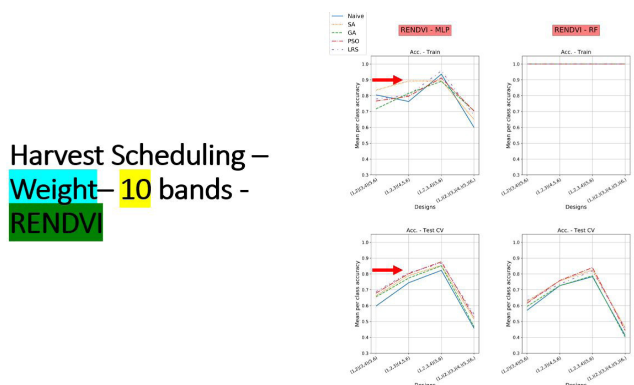
Moving from a greenhouse experiment to a large field study in Geneva, we learned a lot and extensively studied how span-bean spectral response could explain yield and harvest maturity. We conducted UAS flights that captured most important physiological stages of this broad-acre crop over the summer of 2019. We evaluated yield at two stages, namely early and late. We also assessed crop pod maturity level for four different test sets (i.e., class combinations). For this study, we utilized a more robust approach for wavelength selection, which took into account not only correlation between spectral bands, but also the degree to which each is relevant to the objective. We used meta-heuristic optimization algorithms, such as Simulated Annealing (SA), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and plus-L minus-R Stepwise (LRS) approaches and compared the results. The results are showcased in Figures 1-4.

Project Status

Our team is continuing to collect data for the 2020 trial, which tie into current/past results, where we are i) extending results from a past greenhouse study and ii) validating UAS-based findings from 2019 with the aim to publish two more high quality articles based on the two different annual data sets. Finally, for the reported greenhouse study, we published an article in the Journal of Applied Remote Sensing (yield forecasting), as well as one ready-to-be submitted article (growth stage and maturity classification), aimed at the Remote Sensing Journal.

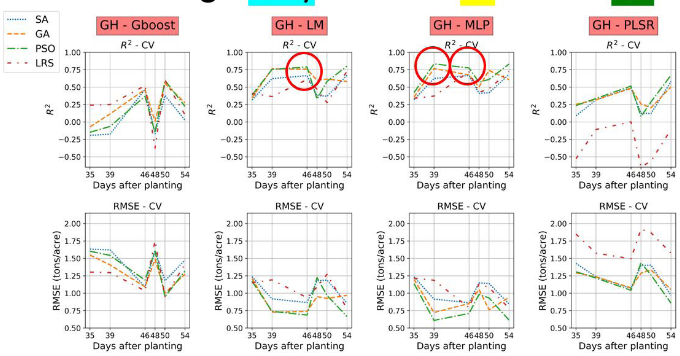


An image of the snap bean field in Geneva, NY, as well as sample spectra.

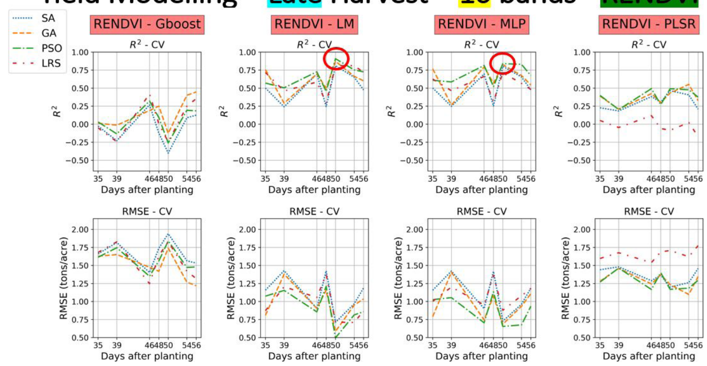


Example of harvest scheduling results, for different algorithms and pod size classes (e.g., 1=immature; 6=over-mature; 5= target harvest size).

Yield Modelling – Early Harvest – 10 bands - GH



Yield Modelling – Late Harvest – 10 bands - RENDVI



Yield modeling results for different algorithms, for the late harvest. Outcomes are expressed as the coefficient of determination (R2) for yield models, while the y-axis represents days after planting, i.e., how well we could predict the eventual harvest outcome, at that stage of the season.

Duck Nest Detection and Species, Age, Sex Classification using Thermal and UV USA-based imagery

Principal Investigator: Jan van Aardt, Carl Salvaggio

Team: Susan Ellis-Felege, Matt Helvey, Tim Bauch, Nina Raqueno

Project Description

Natural resources and wildlife such as ducks draw more than 21M visitors and $3B in revenue to North Dakota (ND). The most important breeding ground for North American ducks, the Prairie Pothole Region, is responsible for 50-80% of all North American ducks. It's also losing 50,000 acres per year. One way to track and manage habitats is to monitor the animal populations in those habitats. The current method for detecting and monitoring breeding duck populations is to use ATVs to drag a 100ft steel chain across the wetlands and scare up the nesting hens, revealing the nest locations. This is both invasive and destructive. The objectives of this research were to i) assess the feasibility of utilizing sUAS based remote thermal (LWIR) imagery to detect active duck nests and ii) determine the feasibility of utilizing remotely sensed ultraviolet (250-400nm) images to classify breeding duck pairs. In partnership with the University of North Dakota and Ducks Unlimited, we went out to ND for a week and collected 500GB of hyperspectral, thermal, LiDAR, and RGB imagery.

Project Status

We developed a detection algorithm utilizing the thermal imagery to automate duck nest detection and recommended improvements. Concurrently, we retrieved duck specimen across a variety of species to obtain UV reflectance measurements in the lab. Ducks and other aviary species have been discovered to both see and reflect strongly in the UV spectrum. We synthesized UAS UV imagery using a spectrometer in a scanning method across the backs of the specimen. Using a Random Forest classifier, we were able to obtain 70-80% classification accuracies for age (binary), sex (binary), and species (one of nine) using panchromatic simulated imagery and demonstrated a 7-8% increase in accuracy when utilizing narrowband UV imagery. We published an IGARSS 2020 Conference Paper on the topic.

UAS pilot Tim Bauch collecting early-morning thermal imagery on the prairies of North Dakota for duck nest detection

(left-to-right) Tim Bauch (RIT), Mason Ryckman (UND), and Dr. Susan Ellis-Felege (UND) inspecting a smaller UAS for duck nest detection, prior to launch

An example of a duck sample, used for UV-based algorithm development by MS student Matt Helvey, to classify duck species, age, and sex.

Deciduous Broad Leaf Bidirectional Scattering Distribution Function (BSDF): Measurements, Modeling, and Impacts on Waveform Lidar Forest Assessments

Principal Investigator: Jan van Aardt

Team: Charles Bachmann, Ben Roth, Nina Raqueno

Project Description

Lidar (light detection and ranging) remote sensing has proven high accuracy/precision for quantification of forest biophysical parameters, many of which are needed for operational and ecological management. Although the significant effect of Bidirectional Scattering Distribution Functions (BSDF) on remote sensing of vegetation is well known, current radiative transfer simulations, designed for the development of remote sensing systems for ecological observation, seldom take leaf BSDF into account. Moreover, leaf directional scattering measurements are almost nonexistent, particularly for transmission. Previous studies have been limited in their electromagnetic spectrum extent, lacked validated models to capture all angles beyond measurements, and did not adequately incorporate transmission scattering. Many current remote sensing simulations assume leaves with Lambertian reflectance, opaque leaves, or apply purely Lambertian transmission, even though the validity of these assumptions and the effect on simulation results are currently unknown. This study captured deciduous broadleaf BSDFs (Norway Maple (Acer platanoides), American Sweetgum (Liquidambar styraciflua), and Northern Red Oak (Quercus rubra)) from the ultraviolet through shortwave infrared spectral regions (350-2500 nm), and accurately modeled the BSDF for extension to any illumination angle, viewing zenith, or azimuthal angle. Relative leaf physical parameters were extracted from the microfacet models delineating the three species. Leaf directional scattering effects on waveform lidar (wlidar) signals and their dependence on wavelength, lidar footprint, view angle, and leaf angle distribution (LAD) were explored using the Digital Imaging and Remote Sensing Image Generation (DIRSIG) model. The greatest effects, compared to Lambertian assumptions, were observed at visible wavelengths, small wlidar footprints, and oblique interrogation angles relative to the mean leaf angle. These effects were attributed to (i) a large specular component of the BSDF in the visible region, (ii) small footprints having fewer leaf angles to integrate over, and (iii) oblique angles causing diminished backscatter due to forward scattering. Opaque leaf assumptions were seen to have the greatest error for near-infrared (NIR) wavelengths with large footprints, due to the increased multi-scatter contribution at these configurations. Armed with the knowledge from this study, researchers are able to select appropriate sensor configurations to account for or limit BSDF effects in forest lidar data.

Project Status

In order to address the lack of knowledge on leaf level BSDF impacts on waveform lidar data, the following objectives were met:

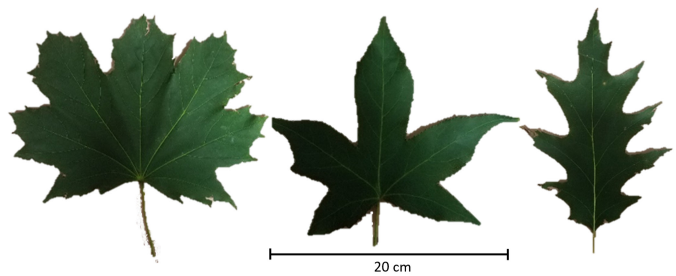
- Assessed a method to accurately and precisely measure leaf BSDF spectrally, from the visible through shortwave-infrared spectral domains;
- Evaluated/Developed BSDF models to extend results to any illumination and viewing zenith or azimuthal angle; and
- Assessed characteristics of broadleaf (deciduous) BSDF and differences between evaluated species.
- Quantified intensity contribution from transmission, i.e., using opaque vs. realistic leaf transmissions with a waveform lidar sensor;
- Determined lidar waveform sensitivity for Lambertian vs. realistic BSDF leaves; and
- Analyzed BSDF effects on LAI, derived from waveform intensity data.

The project has resulted in the following publications:

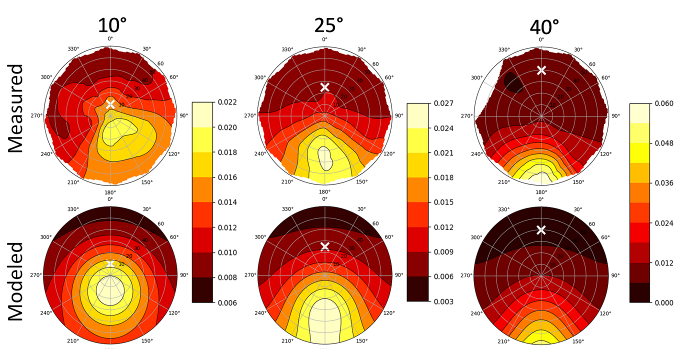
B. D. Roth, M. G. Saunders, C. M. Bachmann, and J. van Aardt, "On Leaf BRDF Estimates and Their Fit to Microfacet Models," IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens., 2020.

B. D. Roth, M. G. Saunders, C. M. Bachmann, and J. van Aardt, "Leaf BTDF Estimates and Models for Select Deciduous Tree Species," IEEE Transactions on Geoscience and Remote Sens., "In Final Review".

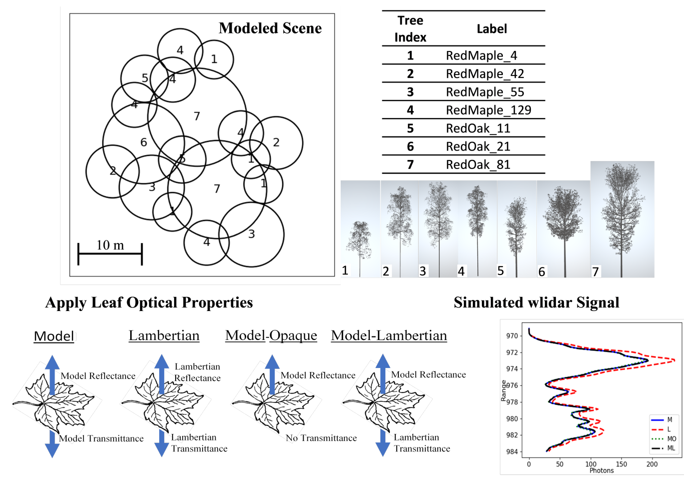
B. D. Roth, A. A. Goodenough, S. D. Brown, M. G. Saunders, K. Krause, and J. van Aardt, "Simulations of Leaf BSDF Effects on Lidar Waveforms" Remote Sensing, "Submitted".



Typical size, shape, and appearance of the three leaf types measured. From left to right (maple, sweetgum, and oak leaf).



BRDF of Oak leaf at 670 nm wavelength estimated from measurements, top row, and model from the regression to microfacet model, bottom row.



Tree Index	Label
1	RedMaple_4
2	RedMaple_42
3	RedMaple_55
4	RedMaple_129
5	RedOak_11
6	RedOak_21
7	RedOak_81

Diagram of the construction of the maple and oak grove. On the top left side of the figure is a map with locations and footprints of the tree models in the scene. The numbers correspond to the tree model index, which is listed in the table on the right side of the figure. Under the table are thumbnail views of each tree model to provide a relative approximation of the shape and size of each tree. The four types of scattering properties are shown on the bottom left and on the right is an example of simulated waveform lidar signals for the four leaf scattering types, model (M), Lambertian (L), model-opaque (MO), and model-Lambertian (ML).

On the Use of Terrestrial Laser Scanning for Structural Assessment of Complex Forest Environments

Principal Investigator: Jan van Aardt

Team: Rich MacKenzie, Ali Rouzbeh Kargar

Project Description

Data were collected from mangrove forests in Micronesia in 2017 and 2019, using the Compact Biomass Lidar (CBL). The sediment accretion were assessed in the lidar data, using the Cloth Simulation Filtering (CSF), followed by filtering the points based on angular orientation, which improved the performance of the ground detection. The elevation change between the two years was found by subtracting the Z values of the nearest points found using Nearest Neighbor Search (NNS; Figure 1). The extreme elevation changes which were due to human interactions or fallen logs were removed using interquartile range analysis. The consistency of TLS-measured elevation changes in comparison to the field-measured ones was found to be 72%, with standard error values being 10-70x lower. Figure 2 shows the result of average elevation change and standard error found across all plots.

Using the same set of data, we detected stems and roots in mangrove forests, and reconstructed them to provide the volume data as an input to biomass model. Figure 3 shows the result of stem and root detection. The consistency of the volume estimation was found to be 85% with an RMSE of 63.65 m3/ha. We also evaluated the diameter-at-breast-height (DBH), using alpha-shape stem construction (Figure 4), which resulted in an average accuracy of 74% and an RMSE of 7.52 cm. One source of deviation between the TLS- and field-measured tree volume and DBH is the fact that not all the trees are measured in-field, due to inaccessibility of these structures (some aboveground roots can be as high as 5 m from the ground). However, the TLS is able to capture these structures and provide more robust results.

Finally, using data collected in Hawaii Volcano National Park (HAVO), we estimated the Leaf Area Index (LAI) using a density-based approach. In this approach, we detect the leaves and branches in the canopy to estimate the LAI. Figure 5 shows the result of leaf and branch segmentation. The accuracy of LAI assessment was found to be 90%, with an average RMSE value of 0.31. Additionally, the linear model obtained from lidar leaf points and the field-measured LAI resulted in an R2 of 0.88. Since not all the data points can be considered spatially uncorrelated, we performed semi-variogram analysis and found the plots with 30 m spacing can be considered spatially independent. We then used linear regression analysis on six sets of data with the plots spacing 30 m apart. The R2 values were found to be between 0.84 and 0.96.

Project Status

The project is complete and resulted in the following documents:

Publications

Rouzbeh Kargar, A.; MacKenzie, R.; Asner, G.P.; van Aardt, J. A Density-Based Approach for Leaf Area Index Assessment in a Complex Forest Environment Using a Terrestrial Laser Scanner. Remote Sens. 2019, 11, 1791.

Rouzbeh Kargar, A.; MacKenzie, R.; Fafard, A.; Asner, G.P.; Krauss, K.W.; van Aardt, J. Surface Elevation Change Evaluation in Mangrove Forests Using a Low-Cost, Rapid-Scan Terrestrial Laser Scanner. Under review in Limnology and Oceanography Methods.

Rouzbeh Kargar, A.; MacKenzie, R.; Apwong, M.; Hughes, E.; van Aardt, J. Stem and Root Assessment In Mangrove Forests Using a Low-Cost, Rapid-Scan Terrestrial Laser Scanner. Under review in Wetlands Ecology and Management.

Fafard, A.; Rouzbeh Kargar, A.; van Aardt, J. Weighted Spherical Sampling of Point Clouds for Forested Scenes. In press in Photogrammetric Engineering Remote Sensing.

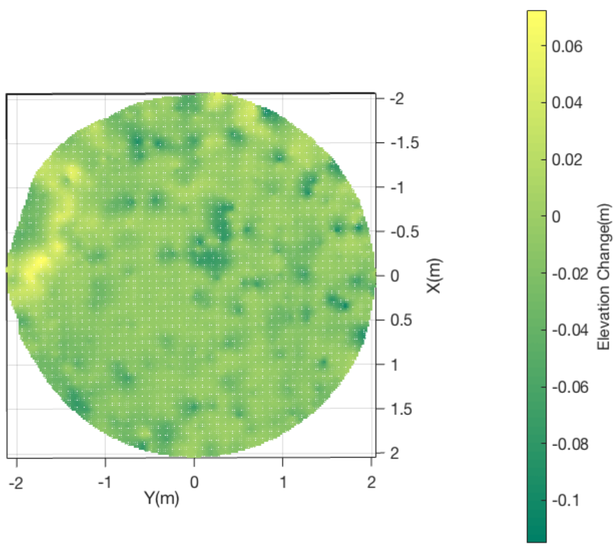
Conference Proceedings

Rouzbeh Kargar, Ali; Mackenzie, Richard; van Aardt, Jan A., Characterizing Stem Volume in Mangrove Forests Using Terrestrial Lidar Scanning. Poster presented at: ForestSat 2018; October 1-5, 2018; College Park, MD, USA.

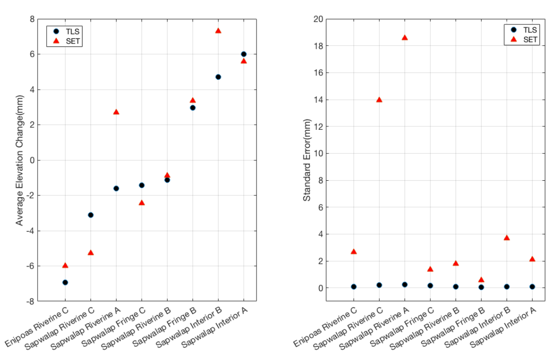
Rouzbeh Kargar, Ali; Mackenzie, Richard; van Aardt, Jan A., Terrestrial laser scanning (TLS) for assessment of mangrove dynamics - root and stem quantification. Poster presented at: Terrestrial Laser Scanning In Forest Ecology; May 6-7, 2019; Gent, Belgium.

Mackenzie, Richard; Krauss, Ken; Cormier, Nicole; Eperiam, Eugene, van Aardt, Jan A., Rouzbeh Kargar, Ali, Sea level rise smack down: 210 Pb vs SET vs LIDAR methodology. Presented at: Mangrove Macrobenthos & Management 2019; July 1-5, 2019; Joyden Hall, Singapore.

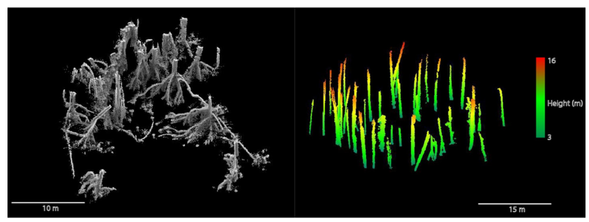
Rouzbeh Kargar, Ali; Mackenzie, Richard; van Aardt, Jan A., Assessment of Aboveground Root Growth and Surface Elevation Changes In Mangrove Forests Using a Rapid-Scan, Low Point Density Terrestrial Laser Scanner. Poster presented at: AGU 2019; December 9-13, 2019; San Francisco, CA, USA.



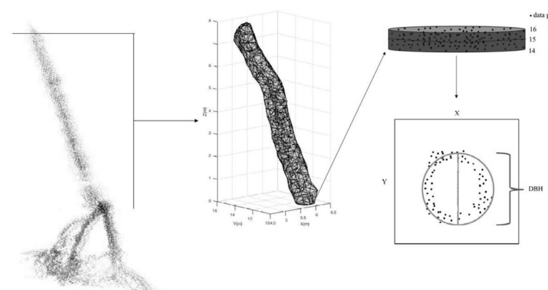
An example of an elevation change product at the plot-scale, where two digital elevation models (DEMs) from different years are subtracted to assess sedimentation loss/gain.



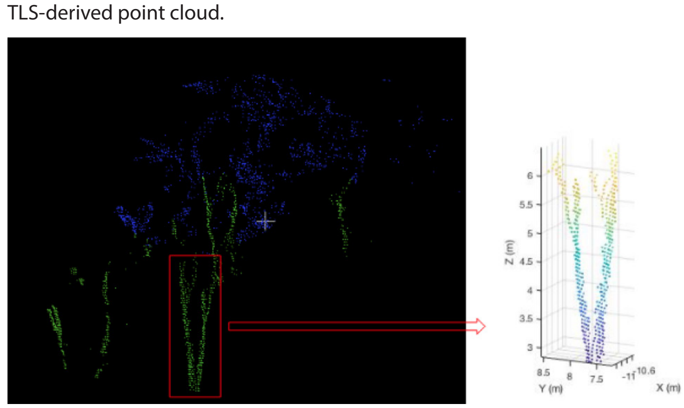
The surface elevation changes, for different plot locations, when comparing our terrestrial lidar system (TLS) approach to the current method using surface elevation tables (SET). (right) Note the increased precision (lower error rates) for the TLS approach vs. the SET method.



The surface elevation changes, for different plot locations, when comparing our terrestrial lidar system (TLS) approach to the current method using surface elevation tables (SET). (right) Note the increased precision (lower error rates) for the TLS approach vs. the SET method.



The use of alpha-shapes to extract a 3D faceted stem structure from a TLS-derived point cloud.



The result of leaf detection in one voxel. The green points represent branches and the blue points show the leaf points.

Toward Accurate Multispectral Corn Simulation for Improved Yield Model Development

Principal Investigator: Jan van Aardt

Team: Quirine Ketterings, Grady Saunders

Project Description

Assessing crop health and, moreover, predicting crop yield from remote sensing imagery is an ongoing area of interest in precision agriculture. We thus pursue a unified spectral-structural model of the growth and development of corn (Zea mays L.) which considers spatiotemporally-varying environmental variables, in pursuit of a theoretically optimal satellite system specification through light-transport simulation with DIRSIG5. Our preliminary objective is to assess the fidelity of a virtual corn field in accurately reproducing spectral response of a spaceborne imaging platform. Our overarching objective is to leverage such a simulation-based approach to perform a spaceborne system-level analysis to establish minimum requirements for assessing corn spectral-structural variability and associated yield-modeling throughout the growing season. The outcomes associated with these objectives could contribute to a definitive specification for optimized corn yield monitoring.

Since beginning work on this project in the summer of 2018, i) we have implemented and improved a geometric parameterization of corn canopy present in the literature, ii) we have developed a preliminary continuous-time growth model to drive the geometric parameterization which is based on discrete-time growth models present in the literature, and iii) in partnership with the USDA and the RIT UAS team, we have collected reference data from a USDA site in Beltsville, Maryland, which we will use to validate the accuracy of the growth model. It may also be worth nothing that we have submitted a proposal to the NASA Goddard Space Flight Center as part of the NASA 2019 Fellowship activity seeking support for the continuation of this project.

Project Status

We have moved on to implement the virtual corn model and associated ray-tracing technique developed in the MS thesis as an official DIRSIG5 software plug-in. Now having the ability to actually edit/add DIRSIG source code, it has become much more feasible to construct technical demonstrations of the simulated corn fields, perform quantitative validation of the simulated imagery, and otherwise achieve the initial objectives of the project. Additional features, such as leaf-angle skewing and in-leaf textural variability, have also been incorporated. That being the case, we recently began a final endeavor to reconstruct the USDA Beltsville DIRSIG5 scenario using the plug-in, and to better model the MicaSense RedEdge-3 multi-spectral sensor, in order to perform a more comprehensive quantitative validation of the virtual corn modeling technique. This validation will be submitted for publication to the MDPI Sensors journal in the near future.

Examples of the 3D corn models, developed by MS student Grady Saunders, toward simulating a remotely-sensed corn field for yield model algorithm development. These images show "striping" and "yellowing" effects, as examples of typical corn physiology during the growing season.

(a) An actual corn field, collected via RIT's MX-1 UAS platform, showing a multispectral MicaSense image; (b) the same scene, but this time rendered as a simulation in DIRSIG-5. Note the clear similarity between the two scenes, due to accurate 3D corn plant models, structure, and radiometry in terms of reflectance and hemispherical scattering properties. The latter scene now can be used to develop algorithms for improved corn yield modeling, by varying the plants' biophysical properties and assessing the effect in spectral signals.

People

The following represents and describes each of our talented list of faculty members, staff, and students. The time and effort from our members allows for the team to be sucessful in our research.

Faculty & Staff

Carl Salvaggio

Director of the Digital Imaging and Remote Sensing Laboratory and Full Professor of Imaging Science, Carl received his Bachelors and Masters degrees in Imaging Science from the Rochester Institute of Technology in 1987 and his Ph.D. in Environmental Resource Engineering from the SUNY College of Environmental Science and Forestry in 1994. Carl teaches and conducts research in image processing, computer vision, remote sensing, and programming. His research interests address the development of solutions to applied, real-world, problems utilizing the appropriate imaging modalities and algorithmic approaches. Carl's expertise are in thermal infrared phenomenology, exploitation, and simulation; design and implementation of novel imaging and ground-based measurement systems; three-dimensional geometry extraction from multi-view imagery; material optical properties measurement and modeling; radiometric and geometric calibration of imaging systems; and still and motion image processing for various applications.

Joesph Sirianni

Associate Director of the Digital Imaging and Remote Sensing Laboratory, Joe received his Bachelors (1992) and Masters (1994) degrees in Imaging Science from the Rochester Institute of Technology. During his 25-year career in the aerospace and defense industry Joe conducted research in image processing algorithms, software development and remote sensing and was a program and business development manager. Joe's continued interest in all-things imaging science, remote sensing and business development drive is a perfect combination for his current role with responsibilities in program management and business development for discovering new sponsored research opportunities for graduate students and research staff.

Charles Bachmann

He received the A.B. degree in Physics from Princeton University, in 1984, and the Sc.M. and Ph.D. degrees in Physics from Brown University in 1986 and 1990, respectively. After a 23-year career at the U.S. Naval Research Laboratory in Washington, DC, Chip joined the RIT Chester F. Carlson Center for Imaging Science faculty as the Frederick and Anna B. Wiedman Chair. Since 2016, he has also served as CIS Graduate Program Coordinator. He holds two U.S. Patents for methods of analysis related to hyperspectral remote sensing imagery. His research interests include hyperspectral and multi-sensor remote sensing applications in coastal and desert environments, BRDF and radiative transfer modeling for retrieval of geophysical and biophysical parameters, field calibration and validation, and the development of advanced instrumentation (goniometers and more recently a mast-mounted hyperspectral video system), as well as abstract models for interpreting hyperspectral and multi-sensor imagery based on manifold descriptions and graph theory.

Tim Bauch

Lab Engineer and sUAS Pilot for the Digital Imaging and Remote Sensing Laboratory, Tim received his Associates degree in Optical Systems Technology from Monroe Community College in 2015 and his Bachelors degree in Imaging Science from Rochester Institute of Technology in 2017. Tim received his Part 107 FAA Pilots license for sUAS Commercial Operations in January 2018. He has performed over 600 flights since that time for many different research projects. His research interests involve using drone technology to solve real world problems to areas such as precision agriculture, infrastructure, environmental science and remote sensing algorithm development. In addition, he has interests in system integration and design for both ground based and UAS Imaging systems. Tim also loves to help and instruct students and is teaching the Freshman Imaging Project in the Chester F. Carlson Center for Imaging Science.

Scott Brown

Head of the Modeling and Simulation group within the Digital Imaging and Remote Sensing Lab. This group focuses on the modeling of airborne and space-based passive and active EO/IR imaging systems. Scott's specific expertise is the mentoring of student and staff re-search projects and the implementation and integration of complex radiation propagation codes. Since 1994, he has been the lead for the physics-driven image and data simulation model called DIRSIG. This model is elaborate software architecture for radiation propagation across the EO/IR region. The capabilities of the model range from passive temperature calculations to active time-gated, LIDAR predictions. The model consists of nearly a million lines of C++ and is externally distributed to government organizations and contractors. Scott routinely conducts on- and off-site training courses that are attended by the professional community regarding the use of the remote sensing modeling and simulation tools developed at RIT and general remote sensing system design and phenomenology.

Byron Eng

One of our newest members, Byron joined the Digital Imaging and Remote Sensing Laboratory as an Assistant Research Scientist in September 2019. He earned a Master's in Mechanical Engineering and Bachelor's degrees in Physics and Atmospheric Sciences from the University of Utah. His thesis work focused on improving temperature predictions of photovoltaic modules through improved convective cooling models. He is interested in applying his expertise in fluid mechanics and heat transfer in research topics such as atmospheric modeling, air quality, remote sensing, renewable energy, and land-air interactions. Byron is an experienced tutor, teaching assistant, and mentor and loves to help students succeed.

Joyce French

Senior Staff Assistant supporting the Center for Imaging Science. Joyce ensures that all of our Graduate Scholarship students have their tuition paid and receive their stipend payments in a timely manner. Sounds simple, but there are more than 100+ graduate to submit paperwork for, yes, that means hard copies! She helps out with questions concerning health and dental coverage, bank accounts, social security numbers and many other numerous student support areas. If Joyce doesn't know the answer, she will find it! Joyce also hires all of our student employees, and perform administrative monitoring and sign off of time cards. Joyce has been at RIT for almost 21 years, the first 5 doing research with Professor Hailstone, the last 15 in her current position. Prior to joining RIT, Joyce was with Eastman Kodak as a Senior Research Assistant in the Research Labs for 31 years.

Michael Gartley

Assistant Research Professor in the Center for Imaging Science. Michael received his Bachelors degree in Physics from Binghamton University in 1995, his Masters degree in Materials Science and Engineering from Rochester Institute of Technology in 1997 and his PhD in Imaging Science from Rochester Institute of Technology in 2007. He teaches multiple graduate level courses, one of which he developed to teach practical approaches to system level design trades he learned from his 10 years in industry prior to entering academia. His research often focuses heavily on low level modeling and simulation of various remote sensing modalities such as panchromatic, polarimetric, spectral, and Synthetic Aperture Radar. Michael is also conducting research to improve detection, characterization and monitoring of resident space objects for improved Space Situational Awareness.

Aaron Gerace

Assistant Research Faculty in the Chester F. Carlson Center for Imaging Science. Aaron completed his Bachelors and Masters degree in Mathematics from Brockport College in 2002 and his Ph.D. in Imaging Science from the Rochester Institute of Technology in 2010. His research in the Digital Imaging and Remote Sensing laboratory focuses on calibration of spaceborne thermal sensors and validation of their corresponding higher level products. An upcoming award will enable him to investigate the impact of future Landsat sensor designs on science applications. He is motivated by challenging problems and the wise words of RATM.

Adam Goodenough

Senior Scientist with the Digital Imaging and Remote Sensing Laboratory and co-devel-oper of the Digital Imaging and Remote Sensing Image Generation (DIRSIG) tool. Adam received his B.S. and Ph.D. degrees in Imaging Science from the Rochester Institute of Technology (RIT) in 2001 and 2007, respectively. His contributions to the remote sensing community were recently recognized with the 2017 USGIF Achievement Award in Aca-demia. His research interests include modeling and simulation, water quality monitoring, and data visualization.

Emmett Ientilucci

Assistant Professor and Graduate Admissions Chair in the Chester F. Carlson Center for Imaging Science. Emmett has degrees in optics and imaging science. Prior to his faculty position, he was a Research Faculty and Postdoctoral Research Fellow for the Intelligence Community. His research interests include, spectral image analysis and variability, hyperspectral image processing, target and shadow detection, radiometric calibration, atmospheric compensation and algorithm development. He has taught courses and labs both at RIT and Monroe Community College. He has 63 publications and has served as referee on 14 journals including being an Associate Editor for a special issue of Optical Engineering. He has been a program reviewer for NASA, the Department of Defense (DOD), and is Chair for the SPIE Imaging Spectrometry Conference, the WNY Geoscience and Remote Sensing Society, and the UAS STRATUS Conference. He is currently working on a text book entitled, "Radiometry and Radiation Propagation" with Oxford University Press.

Daniel Kaputa

Director of Ravven Labs and Assistant Professor of Computer Engineering Technology, Dan received his Bachelors degree in Computer Engineering [2002] and Masters [2004] and PhD [2007] in Electrical Engineering from the State University of New York at Buffalo. Dan teaches and conducts research in FPGA programming, image processing, computer vision, deep learning, and UAVs. His research interests are broken into two distinct categories namely FPGA based on board video processing for GPS denied navigation and object classification and localization via quantized neural networks. His passion is to combine both domains to create a single FPGA based UAV capable of real time object detection for counter UAS applications.

John Kerekes

Professor of Imaging Science and served as past DIRS Director from 2016-2019. John received his BS, MS, and Ph.D. in Electrical Engineering from Purdue University in 1983, 1986, and 1989, respectively. John teaches courses related to probability, statistics, and system modeling in synergy with his research interests in remote sensing system analyses and performance sensitivity studies using simulation and modeling techniques. While his primary expertise is in the area of hyperspectral imaging systems, he has also worked with other remote sensing modalities including thermal imaging, lidar and synthetic aperture radar, with applications ranging from object detection and land cover classification to atmospheric sounding. John is also an active volunteer with the IEEE Geoscience and Remote Sensing Society. Prior to joining RIT, he was a staff member at the MIT Lincoln Laboratory for 15 years.

Tania Kleynhans

PhD. Researcher / Engineer II at the Chester F. Carlson Center for Imaging Science, Tania received a Bachelor's degree in Mathematics and Honors degree in Operational Research from the University of South Africa, and an M.S. and PhD. in Imaging Science at the Rochester Institute of Technology. She works on various research projects including algorithm development for calculating surface temperature from satellite imagery, thermal sensor calibration and band trade studies, pigment identification of hyperspectral data from paintings with machine learning and AI, and the development of a low cost multispectral imaging system and software for historical document discovery. Tania leads the Rochester Cultural Heritage Imaging, Visualization and Education (R-CHIVE) group that focus on using various imaging modalities to uncover faded, erased or damaged historical texts.

Robert Kremens

Dr. Kremens is an atomic physicist by education but has spent most of his career as an instrument physicist designer. In addition to a BS, MS and PhD in physics, he obtained a mid-career MS in Environmental Science. He has a strong history of designing and implementing complex experimental apparatus in government, industrial and academic settings. Bob has broad knowledge in measurement techniques including electronics design and fabrication, transducer interfacing, data acquisition and reduction, optical systems, lasers, pulsed power systems, vacuum systems and mechanical assemblies. Recently he has been engaged in designing and deploying portable, inexpensive, fireproof energy flux measurement for observation of wildland fires. Some of this unique equipment includes multi-pleband infrared radiometers, convective flow gauges that operate in high temperature environments, wide dynamic range data acquisition electronics and multiple band in fire camera systems. He has successfully deployed these sensors hundreds of times in the harsh environment of wildland fire.

Jennifer Lana

Senior Staff Accountant for Sponsored Programs Accounting. Jennifer provides accounting support for grants, gift, endowment, special projects, discretionary and operating accounts as it relates to the Digital Imaging and Remote Sensing faculty and staff. Jennifer received her Bachelor's degree in Business Management from Rochester Institute of Technology in 2010.

Elizabeth Lockwood

As Academic Coordinator for the Chester F. Carlson Center for Imaging Science, Beth's primary role is to assist the Graduate Program Coordinator and the CIS Director with the administration of the Imaging Science M.S. and Ph.D. programs, including scheduling of courses, processing of student actions, and tracking progress toward graduation.

Patricia Lamb

Staff Assistant for the Chester F. Carlson Center of Imaging and Science since 2018. Prior to coming to RIT, she worked for one of the world's largest distributors of electronic components and embedded solutions. With 30 years of experience in an administrative role at a corporate level. Patty supports faculty, staff, students and post-doctoral researchers. Patty husband is a proud alumnus of RIT.

Guoyu Lu

Assistant Professor at the Center for Imaging Science. Prior to joining RIT, Guoyu was a research scientist on autonomous driving at Ford Research and computer vision engineer at ESPN Advanced Technology Group. Guoyu finished his Ph.D. and M.S. in Computer Science at the University of Delaware, with the highest honor from the U. of Delaware (UD) Computer Science department. Before coming to UD, he was in European Master in Informatics (EuMI) Erasmus Mundus program. Guoyu obtained his Master degree in Computer Science at University of Trento and Master degree in Media Informatics at RWTH Aachen University. He finished his Bachelor degree in Software Engineering at Nanjing University of Posts & Telecommunications, with a minor in Business Administration and Management. Guoyu has board research interests spreading across computer vision, robotics, and machine learning and deep learning on the applications of computer vision.

Daniel Mancuso

Senior Financial Analyst for the departments of the Center for Imaging Science, Astrophys-ical Sciences & Technology, Color Science, and Integrated Sciences Academy. Daniel received his bachelor's degree in Accounting and American Politics from RIT, and is pursuing his master's degree in Accounting at RIT as well. Daniel aids the PIs, faculty, and staff in managing the many different sources of funding there are including federal, state, and private grants and contracts, operating funds, discretionary and designated accounts, gifts, endowments, capital, and cascade funds totaling in excess of $25M. He is responsible for providing analysis, projections, and financial, administrative, and policy counsel to the PIs and faculty, as well as senior management, to assist in decision making and strategy.

Donald McKeown

A Project Manager within the Digital Imaging and Remote Sensing Laboratory, Don received a Bachelor's degree in Aerospace Engineering from the State University of New York at Buffalo in 1982. He spent 20 years in industry at Eastman Kodak supporting operations and leading technology development programs for satellite remote sensing pay loads. Since 2001, Don has supported DIRS with program development, program management, and system engineering for a wide variety of projects with an emphasis on airborne (manned and drone) imaging systems.

Colleen McMahon

Senior Staff Assistant for Digital Imaging and Remote Sensing Laboratory, with 10 years of experience in an administrative role, Colleen keeps our lab running with support in office management, event coordination, and logistics, to name a few. Colleen is pursuing a degree in Business Administration from Rochester Institute of Technology. When she is not putting up with our team's shenanigans, Colleen is an active member of the Seneca Siberian Husky Club and serves as team manager, and tournament director for Tri-County Youth Hockey.

David Messinger

Currently a Professor, the Xerox Chair in Imaging Science, and Director of the Chester F. Carlson Center for Imaging Science at the Rochester Institute of Technology. David received a BS in Physics from Clarkson University and a Ph.D. in Physics from Rensselaer Polytechnic Institute. He is an Associate Editor of the journal Optical Engineering and a Senior Member of SPIE. He has published over 150 scholarly articles. His research focuses on projects related to image system analysis and spectral image processing using advanced mathematical approaches with applications to remote sensing and cultural heritage imaging.

Matthew Montanaro

Matt holds degrees in Physics (BS, 2005) and Imaging Science (PhD, 2009) from the Rochester Institute of Technology. He is currently a Senior Research Scientist involved in the calibration of thermal infrared imaging instruments through close ties with NASA Goddard Space Flight Center and the US Geological Survey. He specialized in the calibration of the Thermal Infrared Sensor (TIRS) onboard Landsat 8 and was directly involved in the definition of the calibration methodologies, execution of characterization tests, and anal-yses of instrument performance data, both pre-flight and on orbit. He now serves as the Deputy Calibration Lead for the upcoming Landsat 9/TIRS-2 instrument. He has also sup-ported other NASA missions including the SOLARIS sensor and the New Horizons/LEISA instrument. Matt has a number of peer-reviewed scientific journal publications and confer-ence proceedings and has presented at various remote sensing-related conferences. Additionally, he has supported and advised a number of graduate and undergraduate students.

Nina Raqueño

Assistant Research Scientist for the Laboratory for the past 20 years. Nina received a Bachelors in Imaging Science from the Rochester Institute of Technology in the 1990s. Nina escaped for several years to SUNY College of Environmental Science and Forestry where she learned practical remote sensing tools, such as GIS, GPS, surveying, flight plan-ning, and many of the skills required for field work. During this period, Nina also served as a technical illustrator for "Remote Sensing: The Image Chain Approach". She was eventually lured back to RIT and DIRS by Dr. John Schott with the promise of spending cloud free days on Lake Ontario (which, by the way, is not quite the ocean but at least it's wet). The first project she was assigned to was Landsat 7 thermal calibration which she continues today as part of NASA/USGS's Landsat Calibration Team. Nina continues to coordinate remote sensing field campaigns of all sizes and for a variety of platforms, satellite, aircraft, rooftop, and now from sUAS. Basically, the only thing that has changed in 20 years is now with the advent of sUAS we can fly more often and under those pesky clouds.

Philip Salvaggio

One of our newest members, Philip joined the Digital Imaging and Remote Sensing Lab-oratory as a Senior Scientist in September 2019. He received dual Bachelor's degrees in Imaging Science and Computer Science from the Rochester Institute of Technology in 2012, as well as his Ph.D. in Imaging Science in 2016. His research involved imaging systems quality modeling, with a focus on systems with exotic apertures, such as sparse aperture telescopes. From 2016-2019, Philip was a Principal Engineer at EagleView, developing a scalable imaging processing workflow centered around the problem of dis-tributed aerial triangulation, as well as orthomosaic generation, dense 3D reconstruction and rolling shutter correction. He has also taught programming as an adjunct professor in the Imaging Science department. Philip is joining the Digital Imaging and Remote Sens-ing Laboratory as a Senior Imaging Scientist, where he will be continuing his research on imaging systems modeling as a member of the DIRSIG team. Philip is also an avid fan of ultimate frisbee, darts, and red pandas.

Jan van Aardt

Full Professor in the Chester F. Carlson Center for Imaging Science. Jan obtained a B.Sc. Forestry degree ("how to grow and cut down trees") from the University of Stellenbosch, South Africa in 1996. He completed M.S. and Ph.D. Forestry degrees, focused on remote sensing (imaging spectroscopy and light detection and ranging), at the Virginia Polytechnic Institute and State University, Blacksburg, Virginia in 2000 and 2004, respectively. This was followed by post-doctoral work at the Katholieke Universiteit Leuven, Belgium, and a stint as research group leader at the Council for Scientific and Industrial Research, South Africa. Imaging spectroscopy and structural (lidar) sensing of natural resources form the core of his efforts, which vary between vegetation structural and system state (physiology) assessment. Or stated differently, the interaction between photons and leaves is what really gets him going. He has received funding from NSF, NASA, Google, and USDA, among others, and he has published >70 peer-reviewed papers and >80 conference contributions… or rather, his students have.

Anthony Vodacek

Full Professor of Imaging Science. Vodacek received his B.S. (Chemistry) in 1981 from the University of Wisconsin Madison and his M.S. and Ph.D. (Environmental Engineering) in 1985 and 1990 from Cornell University. His areas of research lie broadly in multi-modal environmental remote sensing with a focus on the coupling of imaging with environmental modeling for application to monitoring both terrestrial and aquatic systems. His specific expertise is in spectral phenomenology, image interpretation, aquatic optics including fluorescence lidar, and wildland fire monitoring. He has extensive collaborations in Rwanda and elsewhere in Africa, where he has worked on various teaching and research projects for over ten years. Vodacek is on the Fulbright Specialist roster, is an Associate Editor for the Journal of Great Lakes Research, is a Senior Member of IEEE, and supports the IEEE Geoscience and Remote Sensing Society global initiative as the dioregional liaison to Africa.

Melanie Warren

Since 2010, a Senior Staff Assistant for the Digital Imaging and Remote Sensing (DIRS) and the Multidisciplinary Vision Research (MVRL) Laboratories. Melanie received her Bachelors in Criminal Justice from Niagara University. This included a semester of study abroad at the University of Copenhagen. Melanie supports faculty, staff, and students with procurement purchases, travel arrangements, processing of reimbursements, lab support, special event coordination, and hospitality. She has served on the committee and chaired the College of Science Staff Advisory Council, COSSAC. Melanie is also the Department Captain for the annual RIT United Way campaign, Go Tigers! Hockey, Football, Rugby, Barrel Racing, are family favorites. As always GO BILLS!!!

Eon Rehman

Rehman Eon received a BSc. from Viterbo University in Mathematical Physics and Chemistry, and his Ph.D. in Imaging Science from the Rochester Institute of Technology (RIT). His research interests include the use of optical remote sensing for the assessment of earth sediments and vegetation, radiative transfer modeling, thermal calibration of air/space-borne imaging sensors, development of surface temperature algorithms, and defining requirements for future Earth Observing systems.

Michael Grady Saunders

Grady is a member of the Modeling and Simulation team in the Digital Imaging and Remote Sensing Lab. He received his Bachelor's degree with honors from East Tennessee State University in 2017, where he majored in Digital Media and minored in Mathematics. He earned a Master's in Imaging Science here at RIT in 2020. Following his graduation, Grady was happy to join the department as an Assistant Research Scientist. His primary role on the Modeling and Simulation team concerns the creation and management of high fidelity virtual environments to serve as inputs to the 5th edition of the Digital Imaging and Remote Sensing Image Generation model, or DIRSIG5. His scientific interests, revolve around stochastic light-transport simulation and procedural modeling techniques in the context of 3D computer graphics and computer generated environments. Prior to the pandemic, he also frequented nearby trampoline parks to hone his flipping skills.

Undergraduate & Graduate Students

Student Name	Degree

Nicholas Bitten | M.S.

From Hamburg, NY, Nicolas received his Bachelors degree in Physics from the Rochester Institute of Technology in 2017. He is currently pursuing his Masters in Imaging Science and is expecting to finish in September 2019. In the Fall, he will begin working at the Night Vision and Electronic Sensors Directorate as a physicist in the Image Processing division. His research interests include thermal remote sensing, computer vision and optics.

Ryan Connal | Ph.D.

Currently a Ph.D. candidate at the Center for Imaging Science. Ryan received his Bachelors degree in Imaging Science from RIT in 2018. In his undergraduate studies, he performed research with Drs. Aaron Gerace and Matthew Montanaro relating to Landsat 8 TIRS calibration. His current research interests involve remote sensing in the visible and thermal infrared, image processing, and computer vision.

David Conran | Ph.D.

Received a B.S. in Astrophysics and Astronomy from the Pennsylvania State University in 2018. His research focus involves the spatial assessment of remote imaging sensors using convex mirrors producing ground-based point sources. In partnership with Labsphere, this technology and research is being brought to the satellite community for easy access to an ideal, stable calibration target, both spatially and radiometrically.

Scott Couwenhoven | M.S.

A first year MS student in the Applied and Computational Mathematics program. Prior to graduate school, he obtained a BS in Mechanical Engineering from RIT. He is currently working on a machine learning approach to cloud shadow mitigation in overhead imagery under Dr. Emmett Ientilucci and has research interests in Deep Learning and Computer Vision.

Rachel Golding | M.S.

MS student, graduated with a BS in Astronautical Engineering from the US Air Force Academy, current Air Force officer transferring to US Space Force soon.

Zhaoyu Cui | Ph.D.

Zhaoyu Cui received the B.S. and M.S. degrees in Electrical Engineering from Harbin Institute of Technology, Harbin, China, in 2011 and 2013. He received the PhD degree in Imaging Science from Rochester Institute of Technology, Rochester, NY in 2019. His research interests include remote sensing imaging system modelling and vegetation geophysical parameter retrieval applications. He is currently a staff image scientist at Omnivision Technologies.

Alex Fafard | Ph.D.

Student Name	Degree
Amir Hassanzadeh	Ph.D.

Amir received his bachelor's degree in chemical engineering from Guilan University in Rasht, Iran and joined RIT and the Imaging Science program in 2017. Amir joined the DIRS group in September 2018 and started working under the supervision of Jan van Aardt. He currently works on yield modeling and harvest scheduling of snap-bean, as a proxy crop using sUAS and remote sensing approaches. His research interests are precision agriculture, remote sensing, hyperspectral data as well as machine learning and deep learning methods. Amir is also keen in briding remote sensing to deep learning. His research so far, up until summer 2019, involved a greenhouse study in RIT as well as field data collection using sUAS in Geneva, NY. His project is one that focuses on transitioning academia to industry by delivering packages to farmers and growers so they can rent a drone, set up the flight lines, sit and relax while watching the drone fly on its own, uploading the data to the software, have a cup of coffee, and take actions based on the given probability map.

Matthew Helvey	Ph.D.

A student in RIT's Imaging Science program pursuing a Master's degree. Matt obtained his bachelor's degree in Mechanical Engineering from Clemson University in South Carolina. He is conducting research into potential remote sensing applications in wildlife conservation. In particular, he is investigating the feasibility of utilizing thermal infrared and UV imagery obtained from small unmanned aerial systems for use in identification of duck nests in the Prairie Pothole region of North Dakota.

Ethan Hughes	M.S.

A current Master's student the Imaging Science program at RIT that engages in remote sensing research in the area of precision agriculture using unmanned aerial systems, silicon based sensors, and machine learning. Before coming to RIT, Ethan worked as a Wireless Design Engineer at JMA Wireless where he worked designing the next generation of radio frequency products for Verizon and Google. Ethan received undergraduate degrees in mechanical engineering and physics from Widener University in 2014. He has years of applied experience with analog electronics, robotics, imaging, and systems engineering.

Peter Jackson	Ph.D.

A PhD student working with Dr. Cristian Linte in the area of Image-Guided Surgery and Navigation. His research is focused on characterizing uncertainty in image-guided renal interventions and assessing techniques to reduce the uncertainty using simulations and experiments.

Ali Kargar	Ph.D.

Ali is a Ph.D. student at Chester F. Carlson Center for Imaging Science. He received his B.E. in Polymer Engineering and Color Science from Amirkabir University of Technology (Tehran Polytechnic) in 2015. Ali's research is focused on structural assessment of complex forest environments using terrestrial laser scanning data. The complexity in these forests introduce challenges to structural evaluation algorithms, thus Ali works on developing approaches to overcome these issues and improve the results acquired from forest inventories in the studied sites.

Student Name	Degree
Salman Khan	M.S.

Aerospace Engineer in the Royal Canadian Air Force (RCAF), Salman received his Bachelor's degree in Electrical Engineering and Management from the University of Ontario Institute of Technology in 2010. After graduation, he worked as a Quality Engineer at Ford Motor Company assembly plant in Oakville, Ontario, Canada. Salman joined the Canadian Armed Forces in 2013 and worked as an In-Service Systems Manager as his first of many postings to come. Deciding to specialize in the field of Aerospace Engineering within the RCAF, he enrolled in RIT as a Masters student in Imaging Science. He is currently conducting his thesis with Dr. Carl Salvaggio. His thesis is on detecting soft story buildings using Google Street View data.

Christopher Lapszynski — Ph.D.

Third year Imaging Science Ph.D. Student, and member of the GRIT Laboratory within the Digital Imaging and Remote Sensing Laboratory, Chris received his bachelors in Imaging Science from Rochester Institute of Technology in 2013. His current research endeavors (soon to include polarization) seek to exploit hyper spectral data sets to derive geophysical parameters obtaining sediment strength and surface trafficability estimates of a scene. Chris' growing expertise are in visible and near infrared phenomenology; design and implementation of novel imaging and ground based systems; material optical properties measurement and radiative transfer modeling, and radiometric calibration.

Chris Lee — Ph.D.

Babak Mamaghani — Ph.D.

Born and raised in Pittsford, NY, Baabak is currently a Ph.D. candidate at the RIT Chester F. Carlson Center for Imaging Science. Baabak received his Bachelors and Masters degrees in Electrical Engineering from RIT in 2014. Baabak conducts research in the radiometric quality of sUAS imagery. His research interests are signal processing, image processing, calibration, multi- and hyperspectral imaging. His dissertation research addresses the question of "how accurate does the data need to be?

Jobin Mathew — Ph.D.

A Ph.D. student at the Center for Imaging Science. Jobin received his Bachelor's degree from University of Kerala, India and his Master's degree in Electrical Engineering at Rochester Institute of Technology. His past research work includes fast text detection and document imaging/processing, spectral calibration of remote sensing data, human eye motion tracking, and forensic blood detection using hyperspectral imagery. He is currently working on change detection in multi/hyperspectral imagery using novel statistical and graph methods along with the application of machine learning techniques.

Emily Meyers — Ph.D.

Emily received her Bachelors degree in Physics from the New College of Florida in 2013 and is currently working on a Ph.D. in Imaging Science at the Rochester Institute of Technology. Her current research interests are in vegetation remote sensing and time-series imaging. For her dissertation, she is investigating how satellite revisit rate impacts our ability to monitor crop growth and predict yield.

Student Name	Degree
Jonathan Miller	Ph.D.

Imaging Science Ph.D. student in the Chester F. Carlson Center for Imaging Science at the Rochester Institute of Technology. Jon holds a Bachelor's degree in Astronautical Engineering from the United States Air Force Academy, and a Master's degree in Imaging Science from the Rochester Institute of Technology. Jon has experience in the design, fabrication, launch, and operations of remote sensing satellites, as well as teaching experience being a former instructor of Astronautics at the United States Air Force Academy. Jon's research interests are in thermal imaging and earth observation remote sensing.

Zachary Mullollan	Ph.D.

A PhD candidate in Imaging Science, Zack Mulhollan earned his Bachelors degree in Imaging Science from Rochester Institute of Technology in 2016. His research interests include multimodal data integration, estimating three-dimensional structures from two-dimensional images, real-world scene simulation, image segmentation, and dynamic object detection and movement prediction.

Cara Murphy	Ph.D.

Currently a part-time Ph.D. candidate in the Chester F. Carlson Center for Imaging Science at RIT, Cara received her Bachelor's degree in Physics and Mathematics at Merrimack College and her Master's degree in Imaging Science from RIT. While working towards her Ph.D., she is also a Lead Engineer at Systems & Technology Research (STR) in the greater Boston area. At both RIT and STR, her interests include signal and image processing of hyperspectral reflectance datasets for material classification, image segmentation, and target detection and classification applications. Specifically, her thesis research investigates various methods for generating high-fidelity spectral libraries for trace chemical residue identification in active spectroscopic imagery.

Nayma Binte Nur	Ph.D.

Nayma Binte Nur is a second-year Ph.D. student at the Center for Imaging Science. She completed her undergrad in Electrical and Electronic Engineering and had her master's in Mathematics. She is currently working in the GRIT laboratory under the supervision of Dr. Charles Bachmann.

Aneesh Rangenekar	Ph.D.

A Ph.D. student at Chester F. Carlson Center for Imaging Science. He received his Masters in Electrical Engineering from Kate Gleason before deciding to join the PhD program with keen interest in remote sensing. His research revolves around dynamic data-driven application for hyperspectral imaging, with focus on aerial object tracking. His research goal is to create an adaptive tracker that can smartly shift between hundreds of spectral bands as required to track an object of specific color and material at real time speed. A few challenges in this approach are shadow, glint, cloud cover and standard occlusion and his research involves tackling these situations one by one before merging them together.

Benjamin Roth	Ph.D.

Ph.D. student, Ben received his Bachelors of Science in Physics from the United States Air Force Academy in 2007 and Masters of Science in Applied Physics in 2012. His Master's thesis focused on atmospheric effects on airborne light detection and ranging (LiDAR). His work experience includes five years at the Air Force Research Laboratory as a research scientist investigating various topics to include ionosphere forecasting, over the horizon radar, and synthetic aperture lidar. Ben's current research is on improving LiDAR data algorithms for forest ecological studies. His emphasis is on characterizing optical properties of deciduous tree leaves for use in LiDAR radiative transfer models.

Student Name	Degree
Cody Webber	Ph.D.

Cody is a Ph.D. candidate with the Digital Imaging and Remote Sensing Laboratory. Cody received his Bachelor of Arts in Physics from Skidmore College in 2016, and attended Dartmouth College where he studied engineering, as well as film and media. Currently, Cody is working on assessing environmental applications of a novel uncooled multispectral thermal remote sensing imager, focusing primarily on land surface temperature retrieval and detection of rogue methane emissions.

Student Name	Degree
Fei Zhang	Ph.D.

Fei received his Bachelor's degree in Optical Information Science and Technology from the Electronic Information School, Wuhan University in 2015 and his master's degree in Optical Engineering from the College of Optical Science and Engineering, Zhejiang University in 2018. Now he is a third-year Ph.D. student under Dr. Jan van Aardt. His current research is using drone-based LiDAR point clouds and multispectral images for precision agriculture applications.

Publications

The following publications are from our hardworking staff members and required hours of dedication and commitment.

Publications

Bibliography

[1] A. Hassanzadeh, J. A. van Aardt, F. Zhang, S. P. Murphy, and S. J. Pethybridge, \Multi-objective wavelength selection for snap-bean yield assessment using remote sensing: A eld study," in AGU Fall Meeting 2020, AGU, 2020.

[2] A. R. Kargar, R. A. MacKenzie, and J. A. van Aardt, "Assessment of aboveground root growth and surface elevation changes in mangrove forests using a rapid-scan, low point density terrestrial laser scanner," in AGU Fall Meeting 2019, AGU, 2019.

[3] A. C. Loui, D. Kloosterman, M. Kucer, N. Cahill, and D. Messinger, "Iterative method for salient foreground detection and multi-object segmentation," Sept. 10 2020. US Patent App. 16-880,505.

[4] Z. Cui and J. Kerekes, "Potential of red edge spectral bands in future landsat satellites on agroecosystem canopy chlorophyll content retrieval," in IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium, pp. 7168-7171, IEEE, 2019.

[5] Z. Mulhollan, A. Rangnekar, A. Vodacek, and M. J. Hoffman, "Occlusion detection for dynamic adaptation," in International Conference on Dynamic Data Driven Application Systems, pp. 337-344, Springer, 2020.

[6] S. Han, J. Kerekes, S. Higbee, L. Siegel, and A. Pertica, "Prediction and assessment comparison for optimizing spectral imaging system design," in IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium, pp. 445-448, IEEE, 2019.

[7] R. T. Ford and A. Vodacek, "Glint correction of unmanned aerial system imagery," in 2019 IEEE Systems and Technologies for Remote Sensing Applications Through Unmanned Aerial Systems (STRATUS), pp. 1-4, IEEE, 2019.

[8] M. Velez-Reyes and D. W. Messinger, "Algorithms, technologies, and applications for multispectral and hyperspectral imagery xxvi," in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 11392, 2020.

[9] M. Velez-Reyes and D. W. Messinger, "Algorithms, technologies, and applications for multispectral and hyperspectral imagery xxv," in Proc. of SPIE Vol, 10986, pp. 1098601-1, 2019.

[10] C. Tyler, S. Goldsmith, R. Eon, R. Brett, C. S. Bachmann, and D. Osgood, "Assessment of salt marsh biophysical properties using high resolution hyperspectral imaging," in 2019 CERF Biennial Conference, CERF, 2019.

[11] J. P. Kerekes, C. D'Angelo, and M. T. Tran, "Impact of covid-19 lockdowns on a global sample of surface pm2. 5 monitor measurements," in AGU Fall Meeting 2020, AGU, 2020.

[12] A. Hassanzadeh, J. A. van Aardt, S. J. Pethybridge, and S. P. Murphy, "Yield modelling and harvest scheduling of snap-bean using remote sensing: A greenhouse study," AGUFM 2019, pp. B31K-2416, 2019.

[13] Y. Lu, Y. Wang, Z. Chen, A. Khan, C. Salvaggio, and G. Lu, "3d plant root system reconstruction based on fusion of deep structure-from-motion and imu," Multimedia Tools and Applications , pp. 1–17.

[14] A. Soni, A. Loui, S. Brown, and C. Salvaggio, "High-quality multi-spectral image generation using conditional gans," Electronic Imaging 2020(8), pp. 86–1, 2020.

[15] M. A. Wulder, T. R. Loveland, D. P. Roy, C. J. Crawford, J. G. Masek, C. E. Woodcock, R. G. Allen, M. C. Anderson, A. S. Belward, W. B. Cohen, et al., "Remote sensing of environment: Current status of landsat program, science, and applications," 2019.

[16] T. Kleynhans, J. K. Delaney, and D. W. Messinger, "Automatic material classification of paintings in illuminated manuscripts from vnir reflectance hyperspectral data cubes," in Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXVI, 11392, p. 113920J, International Society for Optics and Photonics, 2020.

[17] H. Li, L. Pan, E. J. Lee, Z. Li, M. J. Hoffman, A. Vodacek, and S. S. Bhattacharyya, "Hyperspectral video processing on resource constrained platforms," in 2019 10th Workshop on Hyperspectral Imaging and Signal Processing: Evolution in Remote Sensing (WHISPERS), pp. 1–5, IEEE, 2019.

[18] R. Ducay and D. W. Messinger, "Radiometric assessment of four pansharpening algorithms as applied to hyperspectral imagery," in Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXVI, 11392, p. 1139203, International Society for Optics and Photonics, 2020.

[19] S. Huang, D. M. Messinger, and D. Bove, "Hyperspectral analysis: black inks separation in the gough map of great britain," in Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXVI, 11392, p. 113920K, International Society for Optics and Photonics, 2020.

[20] A. M. N. Taufique and D. W. Messinger, "Hyperspectral pigment analysis of cultural heritage artifacts using the opaque form of kubelka-munk theory," in Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXV, 10986, p. 1098611, International Society for Optics and Photonics, 2019.

[21] R. R. Izzo, A. N. Lakso, E. D. Marcellus, T. D. Bauch, N. G. Raqueno, and J. van Aardt, "An initial analysis of real-time suas-based detection of grapevine water status in the finger lakes wine country of upstate new york," in Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping IV, 11008, p. 1100811, International Society for Optics and Photonics, 2019.

[22] S. Han, J. Kerekes, S. Higbee, L. Siegel, and A. Pertica, "Band selection method for subpixel target detection using only the target signature," Applied Optics 14, 2019.

[23] B. Mamaghani, M. G. Saunders, and C. Salvaggio, "Inherent reflectance variability of vegetation," Agriculture 9(11), p. 246, 2019.

[24] S. B. Goldsmith, R. S. Eon, C. S. Lapszynski, G. P. Badura, D. T. Osgood, C. M. Bachmann, and A. C. Tyler, "Assessing salt marsh vulnerability using high-resolution hyperspectral imagery," Remote Sensing 12(18), p. 2938, 2020.

[25] A. Hassanzadeh, S. P. Murphy, S. J. Pethybridge, and J. van Aardt, "Growth stage classification and harvest scheduling of snap bean using hyperspectral sensing: A greenhouse study," Remote Sensing 12(22), p. 3809, 2020.

[26] B. D. Roth, A. A. Goodenough, S. D. Brown, J. A. van Aardt, M. G. Saunders, and K. Krause, "Simulations of leaf bsdf effects on lidar waveforms," Remote Sensing 12(18), p. 2909, 2020.

[27] G. Badura, C. M. Bachmann, J. Harms, and A. Abelev, "Observed relationship between brf spectral-continuum variance and macroscopic roughness of clay sediments," IEEE Transactions on Geoscience and Remote Sensing 57(9), pp. 6726–6740, 2019.

[28] R. T. Ford and A. Vodacek, "Determining improvements in Landsat spectral sampling for inland water quality monitoring," Science of Remote Sensing , p. 100005, 2020.

[29] B. Mamaghani and C. Salvaggio, "Comparative study of panel and panelless-based reflectance conversion techniques for agricultural remote sensing," arXiv preprint arXiv:1910.03734 , 2019.

[30] M. Parente, J. Kerekes, and R. Heylen, "A special issue on hyperspectral imaging [from the guest editors]," IEEE Geoscience and RemoteSensing Magazine 7(2), pp. 6–7, 2019.

[31] D. S. Sinclair Jr, C. Bachmann, and P. Almonte, "Cone with tobacco plug filter," Sept. 17 2019. US Patent 10,412,990.

[32] B. D. Roth, M. G. Saunders, C. M. Bachmann, and J. A. van Aardt, "On leaf brdf estimates and their fit to microfacet models," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 13, pp. 1761–1771, 2020.

[33] Y. Lu, S. Kourian, C. Salvaggio, C. Xu, and G. Lu, "Single image 3d vehicle pose estimation for augmented reality," in 2019 IEEE Global Conference on Signal and Information Processing (GlobalSIP), pp. 1–5, IEEE, 2019.

[34] T. R. Peery and D. W. Messinger, "Panchromatic sharpening enabling low-intensity imaging of cultural heritage documents," in Image Sensing Technologies: Materials, Devices, Systems, and Applications VI, 10980, p. 1098004, International Society for Optics and Photonics, 2019.

[35] A. Fafard, J. Van Aardt, M. Coletti, and D. L. Page, "Global partitioning elevation normalization applied to building footprint prediction," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 13, pp. 3493–3502, 2020.

[36] T. R. Peery and D. W. Messinger, "Spatial resolution as a trade-space for low-light imaging of sensitive cultural heritage documents," Journal of Cultural Heritage , 2020.

[37] C. M. Webber and J. P. Kerekes, "An examination of enhanced atmospheric methane detection methods for predicting performance of a novel multiband uncooled radiometer imager," Atmospheric Measurement Techniques 13(10), pp. 5359–5367, 2020.

[38] Z. Mulhollan, A. Rangnekar, T. Bauch, M. J. Hoffman, and A. Vodacek, "Calibrated vehicle paint signatures for simulating hyperspectral imagery," in Proceedings of the IEEE-CVF Conference on Computer Vision and Pattern Recognition Workshops, pp. 110–111, 2020.

[39] A. Hassanzadeh, J. van Aardt, S. P. Murphy, and S. J. Pethybridge, "Yield modeling of snap bean based on hyperspectral sensing: a greenhouse study," Journal of Applied Remote Sensing 14(2), p. 024519, 2020.

[40] S. Liang, Q. Liu, G. Yan, J. Shi, and J. P. Kerekes, "Foreword to the special issue on the recent progress in quantitative land remote sensing: Modeling and estimation," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 12(2), pp. 391–395, 2019.

[41] C. P. Murphy, J. P. Kerekes, D. A. Wood, and A. K. Goyal, "Practical model for improved classification of trace chemical residues on surfaces in active spectroscopic measurements," Optical Engineering 59(9), p. 092012, 2020.

[42] G. Badura and C. M. Bachmann, "Assessing effects of azimuthally oriented roughness on directional reflectance of sand," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 12(3), pp. 1012–1025, 2019.

[43] A. Rouzbeh Kargar, R. A. MacKenzie, A. Fafard, K. W. Krauss, and J. van Aardt, "Surface elevation change evaluation in mangrove forests using a low-cost, rapid-scan terrestrial laser scanner," Limnology and Oceanography: Methods , 2020.

[44] S. Han, J. Kerekes, S. Higbee, and L. Siegel, "Optimizing requirements for a compact spaceborne adaptive spectral imaging system in subpixel target detection applications," IEEE Journal on Miniaturization for Air and Space Systems 1(1), pp. 32–46, 2020.

[45] R. S. Eon, C. M. Bachmann, C. S. Lapszynski, A. C. Tyler, and S. Goldsmith, "Retrieval of sediment filling factor in a salt panne from multiview hyperspectral imagery," Remote Sensing 12(3), p. 422, 2020.

[46] A. R. Kargar, R. A. MacKenzie, M. Apwong, E. Hughes, and J. van Aardt, "Stem and root assessment in mangrove forests using a low-cost, rapid-scan terrestrial laser scanner," Wetlands Ecology and Management 28(6), pp. 883–900, 2020.

[47] L. Croneborg, K. Saito, M. Matera, D. McKeown, and J. van Aardt, "Digital elevation models: A guidance note on how digital elevation models are created and used-includes key definitions, sample terms of reference, and how best to plan a demmission," 2020.

[48] D. S. Kaputa, T. Bauch, C. Roberts, D. McKeown, M. Foote, and C. Salvaggio, "Mx-1: A new multi-modal remote sensing uas payload with high accuracy gps and imu," in 2019 IEEE Systems and Technologies for Remote Sensing Applications Through Unmanned Aerial Systems (STRATUS), pp. 1–4, IEEE, 2019.

[49] T. Kleynhans, C. M. S. Patterson, K. A. Dooley, D. W. Messinger, and J. K. Delaney, "An alternative approach to mapping pigments in paintings with hyperspectral reflectance image cubes using artificial intelligence," Heritage Science 8(1), pp. 1–16, 2020.

[50] E. Myers, J. Kerekes, C. Daughtry, and A. Russ, "Assessing the impact of satellite revisit rate on estimation of corn phenological transition timing through shape model fitting," Remote Sensing 11(21), p. 2558, 2019.

[51] B. Mamaghani and C. Salvaggio, "Multispectral sensor calibration and characterization for suas remote sensing," Sensors 19(20), p. 4453, 2019.

[52] T. Kleynhans, D. W. Messinger, and J. K. Delaney, "Towards automatic classification of diffuse reflectance image cubes from paintings collected with hyperspectral cameras," Microchemical Journal , p. 104934, 2020.

[53] G. P. Badura, C. M. Bachmann, A. C. Tyler, S. Goldsmith, R. S. Eon, and C. S. Lapszynski, "A novel approach for deriving lai of salt marsh vegetation using structure from motion and multiangular spectra," IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 12(2), pp. 599–613, 2019.

[54] P. Bamurigire, A. Vodacek, and A. Valko, "Simulation of Internet of Things water management for efficient rice irrigation in Rwanda," Agriculture 10(10), p. 431, 2020.

[55] J. Fernandez-Ivern, D. Messinger, and J. M. Hughes, "Systems and methods for screening submissions in production competitions," Sept. 22 2020. US Patent 10,783,458.

[56] R. S. Eon, S. Goldsmith, C. M. Bachmann, A. C. Tyler, C. S. Lapszynski, G. P. Badura, D. T. Osgood, and R. Brett, "Retrieval of salt marsh above-ground biomass from high-spatial resolution hyperspectral imagery using prosail," Remote Sensing 11(11), p. 1385, 2019.

[57] M. P. McClelland, J. van Aardt, and D. Hale, "Manned aircraft versus small unmanned aerial system—forestry remote sensing comparison utilizing lidar and structure-from-motion for forest carbon modeling and disturbance detection," Journal of Applied Remote Sensing 14(2), p. 022202, 2019.

[58] D. Bai, D. W. Messinger, and D. Howell, "A hyperspectral imaging spectral unmixing and classification approach to pigment mapping in the gough & selden maps," Journal of the American Institute for Conservation 58(1-2), pp. 69–89, 2019.

[59] A. Rouzbeh Kargar, R. MacKenzie, G. P. Asner, and J. Van Aardt, "A density-based approach for leaf area index assessment in a complex forest environment using a terrestrial laser scanner," Remote Sensing 11(15), p. 1791, 2019.

[60] A. Fafard, A. R. Kargar, and J. van Aardt, "Weighted spherical sampling of point clouds for forested scenes," Photogrammetric Engineering & Remote Sensing 86(10), pp. 619–625, 2020.

[61] M. A. Wulder, T. R. Loveland, D. P. Roy, C. J. Crawford, J. G. Masek, C. E. Woodcock, R. G. Allen, M. C. Anderson, A. S. Belward, W. B. Cohen, et al., "Current status of landsat program, science, and applications," Remote sensing of environment 225, pp. 127–147, 2019.

[62] E. Seifert, S. Seifert, H. Vogt, D. Drew, J. Van Aardt, A. Kunneke, and T. Seifert, "Influence of drone altitude, image overlap, and optical sensor resolution on multi-view reconstruction of forest images," Remote sensing 11(10), p. 1252, 2019.

[63] C. M. Bachmann, R. S. Eon, C. S. Lapszynski, G. P. Badura, A. Vodacek, M. J. Hoffman, D. McKeown, R. L. Kremens, M. Richardson, T. Bauch, et al., "A low-rate video approach to hyperspectral imaging of dynamic scenes," Journal of Imaging 5(1), p. 6, 2019.

[64] "AeroRIT: A New Scene for Hyperspectral ImageAnalysis", A. Rangnekar, N. Mokashi, E. Ientilucci, C. Kanan, and M. Hoffman, Transactions on Geoscience and Remote Sensing (TGARS), Vol. 58, No. 11, Pages 8116-8124, (2020), DOI: 10.1109-TGRS.2020.2987199.

[65] "Change Detection in Satellite Imagery with Region Proposal Networks", Andreas Savakis, Navya Nagananda, John Kerekes, E. Ientilucci, Russell Blue, William Hicks, Todd Rovito and Erik Blasch, Journal of the DSIAC Defense Systems Information Analysis Center, Vol. 6, No. 4, (2019).

[66] "Review of Global Near Real- time PM2.5 Estimates and Model Forecasts" , J. Kerekes, M. Patel, C. D'Angelo, 2020 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 5570-5573, IEEE, 2020

Sabbatical

Professor John Kerekes

National Academies Jefferson Science Fellow

Professor John Kerekes spent the 2019-2020 academic year on sabbatical leave as a National Academies Jefferson Science Fellow at the U.S. Department of State in Washington, DC. Prof. Kerekes served as a science advisor to the Greening Diplomacy Initiative (GDI) within the Bureau of Management. While his daily work environment was quite different pre- and post-COVID-19, it was truly a fulfilling experience and he was fortunate to have contributed in a number of ways to the Department's mission.

During the year his primary efforts focused on the use of remote sensing and earth observation to help with environmental monitoring activities within the State Department. The office where he served manages a network of regulatory grade air quality monitors at over 60 overseas U.S. embassies and consulates. These units sample the air for concentrations of particulate matter smaller than 2.5 microns in diameter (PM2.5). Prolonged exposure to high levels of PM2.5 is known to lead to adverse health effects. The State Department established this network primarily for the health and safety of its staff and their families, but also to showcase U.S. technology and to raise awareness about the hazards of air pollution with the general public. In a partnership with the U.S. Environmental Protection Agency they publish the data openly on EPA's AirNow website. This program has led to many opportunities for eco-diplomacy with host countries and the promotion of sustainable activities worldwide.

Prof. Kerekes advised State on how to obtain environmental data from satellites to complement these ground measurements. In some cases, he connected State Department personnel with scientists at NOAA and NASA who assisted with analyses to understand extreme events such as dust storms, and in others he helped to provide access to global air quality forecasts for use by the overseas posts. Prof. Kerekes also led the selection and matching process for the State Department's Virtual Air Quality Fellows, a program that pairs U.S. scientists with embassies and consulates to provide volunteer support for air quality topics. He plans to continue to assist with this program after his sabbatical.

A highlight of the year was the opportunity to present a public lecture at the National Academies of Sciences, Engineering, and Medicine. His topic was "Earth Observing Technologies and Their Role in Supporting Public Policy." The lecture conveyed to a general audience the capabilities and limitations of satellite remote sensing. It also included a number of examples of how commercial satellite imagery can shed light on atrocities and environmental satellite data can be used to monitor the impact of public policies on land use.

Other activities during the year included the following: serving as a member of the U.S. Group on Earth Observation delegation to the Geo Week Ministerial Summit in Canberra, Australia; contributing to one of the largest citizen science campaigns, Earth Challenge 2020, organized in celebration of the 50th anniversary of Earth Day; representing the State Department in their efforts to support an upcoming NASA satellite mission on air quality, MAIA, by assisting with arrangements to provide ground instrument support at overseas posts; and assisting with submissions to the interagency Satellite Needs Survey, a biennial exercise soliciting observational needs from federal civil agencies to help inform NASA's earth observation program.

It was an honor to have worked with many dedicated civil servants and foreign service officers who truly care about their mission and faithfully represent the United States in all they do. Prof. Kerekes plans to continue working with the State Department and will be integrating his experiences into his teaching and student advising.