RIT | College of Science
Chester F. Carlson Center for Imaging Science

Annual Report 2019-2020

Cover photo courtesy of Frank Cost, professor in the School of Photographic Arts and Sciences. This drone photo was taken at the 30th anniversary reunion of the Center for Imaging Science, October, 19, 2019.

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Foreword

David W. Messinger, Ph.D.

Welcome to the 2019 - 2020 Academic Year Annual Report of the Chester F. Carlson Center for Imaging Science! This past year, or at least the second half of it, was a particular challenge for the Center due to the Coronavirus Pandemic. However, despite all the challenges the pandemic imposed, we continued to deliver an outstanding educational and research program in Imaging Science. This is largely due to the amazing efforts of the students, faculty, and staff in the Center, and we are grateful for everyone's contributions to this challenging year.

Of course, long before the pandemic changed all of our lives, in October 2019 we celebrated the 30th anniversaries of both the opening of the Chester F. Carlson Center for Imaging Science building, as well as the approval of the Ph.D. program. The Ph.D. in Imaging Science was the first ever Ph.D. program at RIT, housed in a new, state-of-the-art building. Over Brick City weekend, we welcomed over 200 Imaging Science, Photographic Science, and Color Science alumni back to RIT. We opened the Center for tours of the ongoing research programs, had students present posters of their research, and generally had a great time getting caught up. In the evening we all met for a great banquet that included remarks from the Dean of the College of Science and past President Al Simone. Also in attendance were the Provost, members of the Board of Trustees, and the Vice Presidents of both Government and Community Relations and Research. At the end of the night, we were treated to a presentation by Dr. John Schott on the history of the Center and the Imaging Science degree programs. His presentation was based on his book, titled "Coming of Age," published in the Fall of 2019 by RIT Press. Photos from the event can be seen throughout this report.

Our faculty, staff, and students continue to be recognized for their outstanding work in the field of Imaging Science. Emeritus Professor Roger Dube was given the 2019 Ely S. Parker Award by the American Indian Science and Engineering Society (AISES), recognizing scientists and engineers providing exceptional service to the American Indian / Alaska Native community. John Kerekes spent the year at the United States Department of State serving as a Jefferson Science Fellow. He primarily supported efforts related to remote sensing and air quality. In January 2020 Zoran Ninkov took a position as a Program Manager at the National Science Foundation using his expertise in imaging and astrophysics to help the government agency evaluate future research opportunities. Additionally, alumni and current staff member Matt Casella received the Rising Star Award as part of the RIT Presidential Awards for Outstanding Staff honors.

In addition to our faculty and staff, our students have also been very productive this past year. Three Imaging Science Ph.D. students, Rakshit Kothari, Aayush Chaudhary, and Manoj Acharya, won an international competition held by Facebook Research to develop more effective eye-tracking solutions. They presented their work at the 2019 OpenEDS Workshop: Eye Tracking for VR and AR at the International Conference on Computer Vision (ICCV) in Seoul, Korea on Nov. 2. Our Imaging Science Club also ran their first ever hackathon. Seven teams of students competed in the 24-hour challenge to solve an image processing challenge presented by the Rochester-based company EagleView, which offered $5,250 in prizes. EagleView provided the students with a data set of thousands of images of single-family homes across the U.S. and asked them to develop ways to analyze the data and extract meaningful information from it.

Of course, starting in the middle of March we were faced with the challenges presented by the coronavirus pandemic, forcing the RIT campus to be closed, and all instruction to be held online. By the middle of the summer, the research laboratories were back open and the research program was up and running, albeit with significant health and safety restrictions in place. But the Imaging Science program continued with great success in these trying times!

Despite the challenges of a global pandemic, the faculty, staff, and students in the Center continue to build a community of Imaging Science, celebrating our past and building our future. I hope this report finds you healthy and well, and brings you up to speed on the activities in the Chester F. Carlson Center for Imaging Science. Please stop by the Center for a visit whenever you are in the Rochester area. We would love to show you around!

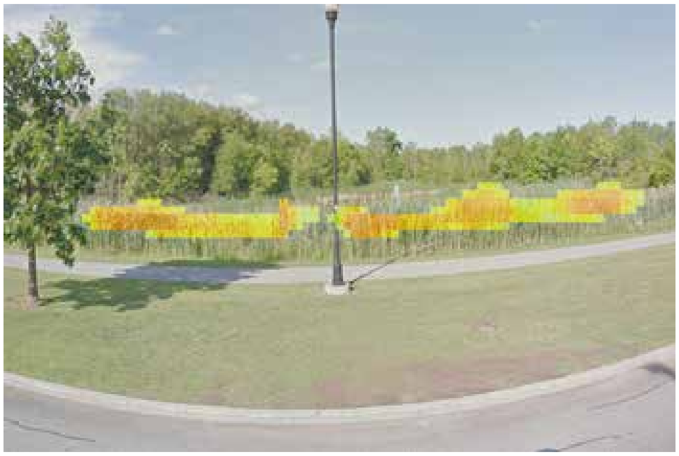
David W. Messinger

News

Stories from RIT News

A Year in Review

July 10, 2019



RIT Scientists Using Technology to Fight Invasive Plants **by Tim Louis Macaluso, City Newspaper**

City Newspaper reports on work by Assistant Professor Christopher Kanan and Associate Professor Christy Tyler, both in the College of Science.

"Kanan and Tyler are creating maps by developing computer algorithms that analyze high-resolution imagery taken from Google Street View. The mapping will show the locations and growth patterns of five highly invasive plants in the Finger Lakes region and Adirondack Park: common reed, Japanese knotweed, giant hogweed, tree-of-heaven, and purple loosestrife."

August 6, 2019

Thirty years of imaging science at RIT

Thirty years after the Center for Imaging Science building was dedicated, it is now home to more than 150 students studying imaging science at the undergraduate and graduate level.

September 10, 2019

'Global Women of Light' to gather for international symposium at 2019 Frontiers in Optics

WiSTEE Connect is collaborating with the Optical Society Foundation to organize the fourth international symposium "Global Women of Light" at the 2019 Frontiers in Optics on Sept. 15. Jie Qiao, an associate professor in RIT's Chester F. Carlson Center for Imaging Science and founder and chair of WiSTEE Connect, will provide an introduction on WiSTEE's visions and activities.

October 4, 2019

photo by Devon Watters

American Indian Science and Engineering Society gives RIT professor its highest honor

Professor Emeritus Roger Dube is the winner of the American Indian Science and Engineering Society's annual Ely S. Parker Award. The award recognizes engineers, scientists and educators who have provided exemplary service to the American Indian/Alaska Native community.

October 8, 2019

RIT Presidential Awards for Outstanding Staff honors Matt Casella **by Vienna McGrain**

RIT honored employees with the annual Presidential Awards for Outstanding Staff. The Rising Star Award was awarded to Matthew Casella, coordinator of administrative laboratory operations in the Chester F. Carlson Center for Imaging Science. The Rising Star Award recognizes a staff member with three years or fewer of service to the university who gives high-quality service, has demonstrated a willingness to collaborate with colleges and university constituents and embodies the RIT spirit by showing imagination, creativity and innovation.

October 15, 2019

Lakes worldwide are experiencing more severe algal blooms **by Terra Daily staff writers**

Terra Daily features research by Nima Pahlevan '12 Ph.D. (Imaging Science). The team "used 30 years of data from NASA and the U.S. Geological Survey's Landsat 5 near-Earth satellite, which monitored the planet's surface between 1984 and 2013 at 30 meter resolution, to reveal long-term trends in summer algal blooms in 71 large lakes in 33 countries on six continents."

October 22, 2019

photo by A. Sue Weisler

RIT researchers win first place in international eye-tracking challenge by Facebook Research

A team of Rochester Institute of Technology researchers took the top prize in an international competition held by Facebook Research to develop more effective eye-tracking solutions, the OpenEDS Challenge. With support from their advisors, three imaging science Ph.D. students—Kothari, Chaudhary, and Manoj Acharya of Nepal—devoted a month of their research time to develop the solution. They ran countless models over that span, continually refining their approach and pulling ahead in the challenge on the final day of competition.

October 28, 2019

'Coming of Age' describes how a signature program shaped RIT's future **by Susan Gawlowicz**

A new book published by RIT Press documents RIT's trajectory from a teaching institute to a research university with an expanding portfolio of doctoral programs. *Coming of Age: The Center for Imaging Science at Rochester Institute of Technology*, by RIT professor emeritus John Schott, describes the university-wide impact of the center and first Ph.D. program.

November 14, 2019

photo by Gabrielle Plucknette-DeVito

Alumni reflect 30 years after Chester F. Carlson Center for Imaging Science opened its doors

The Chester F. Carlson Center for Imaging Science became the only place in the world where students could pursue degrees in the interdisciplinary field of imaging science when it opened its doors in 1989. Thirty years later, alumni returned to campus for a celebration and interactive open house during Brick City Homecoming and Family Weekend.

January 17, 2020

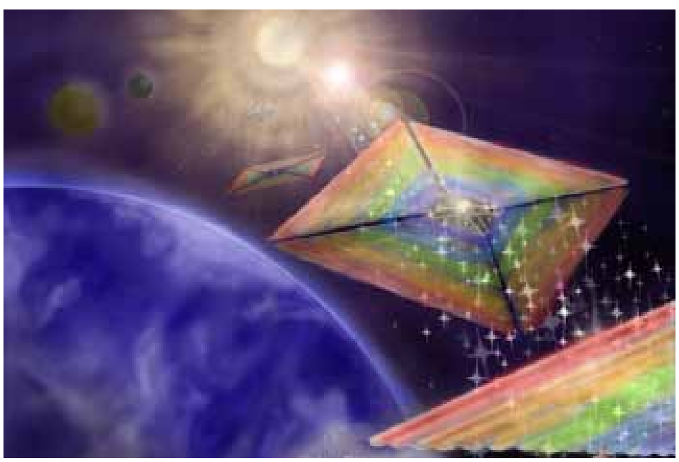
photo by Jesse Wolfe

Glass-color science crossover underscores RIT's collaborative setting

by Aaron Garland

Rachael Strittmatter, a fourth-year Glass student, found a useful application of color to her thesis research of "residue" — which stems from an interest in things unnoticed and what is left behind, she said. Strittmatter leveraged an additional resource on campus to support her research: the Chester F. Carlson Center for Imaging Science (CIS). Through working with CIS associate director Karen Braun, Strittmatter connected with James Ferwerda, associate professor in RIT's College of Science, to investigate color in the use of newspaper pads during glassblowing.

December 27, 2019



MacKenzi Martin/Grover Swartzlander

'Beam rider' technology keeps solar sails aligned

by Isabelle Dumé, Physics World

Physics World cites work by Grover Swartzlander, professor in the Chester F. Carlson Center for Imaging Science. "A team of researchers in the US has now taken a step towards a more powerful light sail by testing a prototype design that uses lasers and diffraction gratings rather than the sunlight and mirrors employed previously."

January 24, 2020

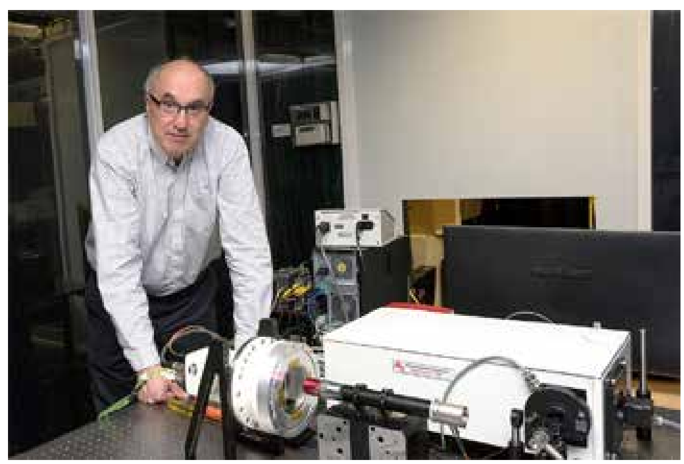
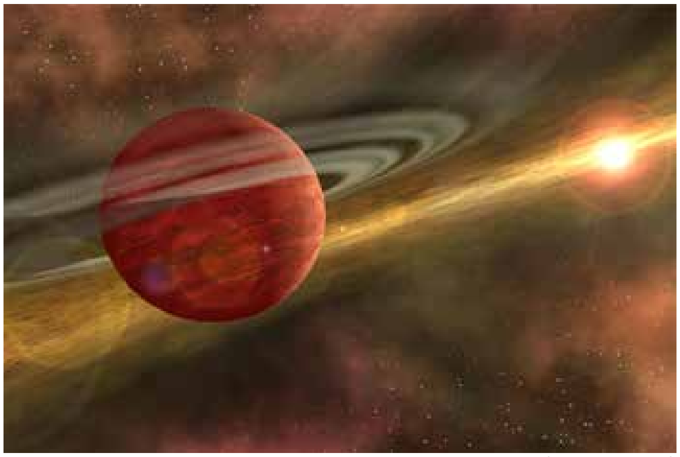


photo by A. Sue Weisler

RIT professor Zoran Ninkov tapped to support NSF as a program director

The National Science Foundation is bringing in RIT Professor Zoran Ninkov, an expert in imaging and astrophysics, to help the government agency evaluate future research opportunities.

February 10, 2020



NASA/JPL-Caltech/R. Hurt (SSC-Caltech)

RIT scientists discover the nearest-known 'baby giant planet'

Scientists from RIT have discovered a newborn massive planet closer to Earth than any other of similarly young age found to date. The baby giant planet lies only about 330 light years from our solar system. The discovery, published in the Research Notes of the American Astronomical Society, provides researchers an exciting new way to study how gas giants form. Joel Kastner, professor of Carlson Center for Imaging Science and School of Physics and Astronomy co-authored the paper.

March 4, 2020

photo by A. Sue Weisler

RIT professor designated as an American Astronomical Society Fellow

An RIT professor is being honored as one of the first American Astronomical Society Fellows. Joel Kastner, a professor in RIT's Chester F. Carlson Center for Imaging Science and School of Physics and Astronomy, is part of an initial group of more than 200 Legacy Fellows recently named by the society.

February 17, 2020

Strong presence by RIT faculty and alumni at Imaging Science symposium

Imaging Science had a strong presence during a recent symposium including a newly established conference organized by former Ph.D. students. Dr. Jan van Aardt was one of two keynote speakers, and gave a comprehensive talk about "Managing crops across spatial and temporal scales — the roles of UAS and satellite remote sensing."

March 31, 2020

photo by A. Sue Weisler

Alumni Update: Returning to guide the next generation of imaging scientists

Karen Braun '96 Ph.D. (imaging science) returned to her RIT roots in August as the associate director for the Chester F. Carlson Center for Imaging Science. Braun is the first woman to earn her Ph.D. at RIT.

April 18, 2020

photo by Jaime Huynh

Student to Student: Artificial intelligence/machine learning

During an internship, Tyler Hayes used computer vision and machine learning techniques to estimate the quality of images taken from airborne image sensors. It sparked her interest to learn more about machine learning, so she applied to the Imaging Science Ph.D. program at RIT.

April 23, 2020

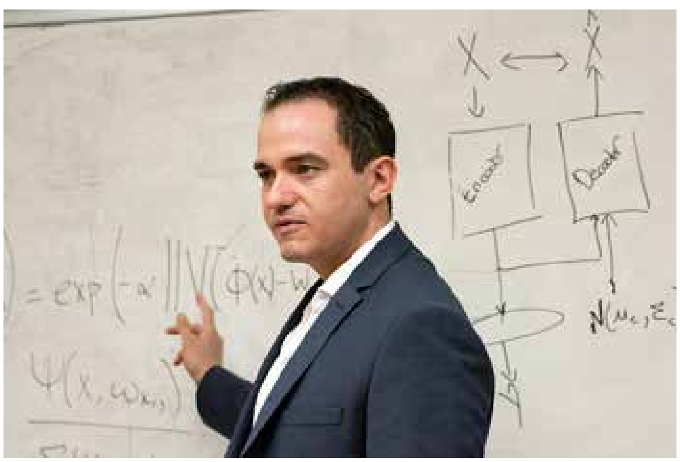


photo by A. Sue Weisler

Fixing the forgetting problem in artificial neural networks

An RIT scientist has been tapped by the National Science Foundation to solve a fundamental problem that plagues artificial neural networks. Christopher Kanan, an assistant professor in the Chester F. Carlson Center for Imaging Science, received $500,000 in funding to create multi-modal brain-inspired algorithms capable of learning immediately without excess forgetting.

April 24, 2020

Austin Powder

Researchers using drones to detect noxious gas released by explosions

Ohio-based explosives company Austin Powder has turned to RIT scientists for a creative approach to quantifying nitrogen oxide gases that on rare occasions are released during mining operations. These chemical compounds can cause serious damage to humans, wildlife, and the environment.

Researchers led by assistant professor Emmett Ientilucci are developing ways to use drones to quantify how much NOx is produced by these explosions.

May 1, 2020

photo by Gabrielle Plucknette-DeVito

First-year students develop imaging system to study historical artifacts

A multidisciplinary team of first-year students has been working to develop an imaging system that can reveal information hidden in historical documents for their Innovative Freshmen Experience project-based course. But with the shift to remote classes, the students left campus with the device nearly complete. Although disappointed, they shifted focus to the opportunities the new situation would create.

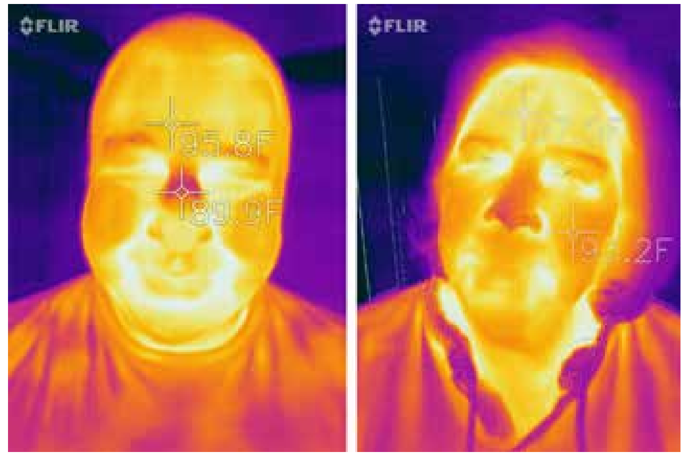
May 15, 2020

photo by Jaime Huynh,

Student to Student: Remote Sensing

RIT student, Benjamin Roth, credits his mentors for his interest in remote sensing. His research focuses on retrieving accurate biophysical information on forest health from remote sensing platforms. "Specifically, I am studying the effects leaf optical properties have on signals received from these systems."

May 30, 2020



Screening for Fevers with Thermal Imaging Technology

As the country continues to reopen, ensuring the health and safety of public areas remains a critical concern. Thermal imaging technology is one screening tool being utilized as part of a comprehensive health program. "This technology can go a long way in helping us get back to normal," said RIT professor and Director of the Digital Imaging and Remote Sensing (DIRS) laboratory, Carl Salvaggio.

May 19, 2020

photo by Devon Watters

RIT Professor Emeritus Roger Dube receives Fulbright Fellowship

Professor Emeritus Roger Dube was recently awarded a prestigious Fulbright fellowship for a project to increase retention of First Nations students in STEM higher education programs. The project will take place at the University of Manitoba, where he is serving as Visiting Indigenous Scholar.

June 5, 2020

photo by A. Sue Weisler

RIT faculty earns NIH grant to use virtual reality to help stroke patients regain lost vision

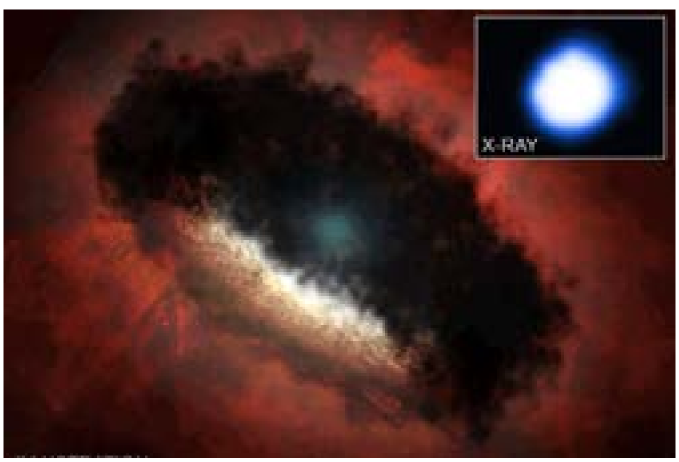
Scientists from RIT and the University of Rochester aim to use virtual reality to help restore vision for people with stroke-induced blindness. The team of researchers, led by associate professor Gabriel Diaz, received a grant from the National Institutes of Health to develop a method they believe could revolutionize rehabilitation for patients with cortically induced blindness. a method they believe could revolutionize rehabilitation for patients with cortically induced blindness, which afflicts about 1% of the population over age 50.

June 18, 2020

Hubble Provides Holistic View of Stars Gone Haywire

NASA features Joel Kastner, a professor in RIT's Chester F. Carlson Center for Imaging Science and School of Physics and Astronomy, and astrophysical science and technology Ph.D. students Jesse Bublitz and Paula Moraga on their latest Hubble telescope observations.

June 18, 2020



NASA/CXC/Aix-Marseille University/N. Grosso et al.; NASA/CXC/M. Weiss

X-rays From a Newborn Star Hint at Our Sun's Earliest Days

NASA mentions Joel Kastner, professor in the Chester F. Carlson Center for Imaging Science and School of Physics and Astronomy, and alumnus David Principe '10 Ph.D. (astrophysical science and technology) for being part of a team that observed an X-ray flare from a very young star using NASA's Chandra X-ray Observatory.

June 23, 2020

RIT building imaging systems to help libraries and museums uncover lost texts

Scientists from RIT are developing affordable imaging systems to help libraries and museums preserve and expand access to their historical collections. The project, funded by a grant from the National Endowment for the Humanities, aims to create a low-cost spectral imaging system and software that can be used to recover obscured and illegible text on historical documents. Collaborators on the project include David Messinger, director and principal investigator of the grant, Tania Kleynhans, associate scientist, Roger Easton Jr., professor, and Juilee Decker, associate professor in the College of Liberal Arts and director of the museum studies program.

These stories appeared in RIT News. Read the full articles at **https://www.rit.edu/science/news**. *Except where indicated, news stories were written by* **Luke Auburn**, *Senior Communication Specialist.*

Academics

Undergraduate Program Update

Undergraduate Program Update

by Dr. James Ferwerda, Undergraduate Program Coordinator

Over the past year we've continued to reap the benefits of the changes we made to "open the front-end" of the curriculum to accommodate more internal change-of-program students and external transfers. In addition to a having larger than average freshman class of twelve this year, we've added five additional students to our first-year cohort. Many of these students came to us through the College of Science's "Science Exploration" program in which students sample from a variety of science disciplines before deciding on a major.

A new development in the curriculum this year is the addition of Special Topics course IMGS-289 on Cultural Heritage Imaging led by Dave Messinger and post-doctoral researcher Tania Kleynhans. The course, which focuses on both the technologies and applications of imaging to the measurement and analysis of cultural heritage objects such as paintings and manuscripts has drawn students from the sciences as well as students from other programs with interests more related to understanding the cultural and historical import of such objects. The course has also made connections to ongoing research projects in the Center including multispectral imaging of palimpsests led by Roger Easton, and work on 3D surface appearance capture and rendering led by James Ferwerda.

Finally, the greatest changes to our undergraduate program this year are not those which we have chosen for ourselves, but those that have been thrust upon us by the global pandemic. It has been an "interesting" year (in the sense of the aphorism about living in interesting times), but the students, staff, and faculty of the Center have adapted remarkably to the changing circumstances and have pulled together admirably to continue our mission of providing world-class classroom and research experiences for our students. Beginning in March, we rapidly pivoted to a mixture of in-class, hybrid, and fully online instruction, which we continue until the current time. This has required a major up-tick in the use of electronic presentation and recording technologies, which have been admirably supported by CIS computing staff Brett Matzke and Jim Bodie, as well as the reconfiguration of classrooms and teaching labs by program graduate and staffer Matt Casella. While we're all looking forward to the end of the pandemic and a time when we can return to the close interpersonal and hands-on teaching/learning experiences that our program is known for, this time has also given us new skills and a new level of adaptability that should also serve us well going forward.

Innovative Freshman Experience

The Innovative Freshman Experience Project is a unique, immersive, hands-on engineering project for incoming freshmen. The goal of the experience is to build an end-to-end imaging system based on a real-world problem. The students form bonds with their classmates, learn project management skills such as setting timelines and work breakdown structures, and learn how to ask the right questions and actively seek out the answers.

This year's freshman class was tasked to build an imaging system to undercover hidden text, known as palimpsests, in ancient documents. Parchments were expensive and time-consuming to make, so often they were repurposed by mechanically or chemically removing the original text and rewriting on them. The removed text can sometimes be recovered by illuminating the parchments with various wavelengths of light. It has been found that UV light works very well, as the iron gall ink used has corrosive properties that cause the areas of removed text to suppress any light, while the parchment fluoresces. Students were asked to build a system with UV illumination, an array of filters through which the reflected light passes, a hi-res capture system, and a computer system for analysis.

During the two-semester class, students studied various illumination sources looking for one that would be bright enough to overcome the low signal-to-noise ratio of only capturing the fluorescent reflectance. However the light had to be safe for observers and the parchments. They ended up with two fluorescent flood lights which gave good uniformity of illumination and strong reflected brightness. Midway through the project, students were challenged to confirm that the effect they were seeing was indeed fluorescence and not just the blue of the lights reflecting off the parchment. They performed multiple experiments on various color measurement devices and fluorometers to confirm that it was fluorescence.

Students also investigated different cameras to determine which would have a high spatial resolution, high signal-to-noise ratio (would work well in low light conditions), and an appropriate focal distance. They also created a structure for mounting the illumination and camera which can be adjusted to different heights. Unfortunately, the students were unable to finish the project due to a campus-wide shut-down associated with Covid-19. They spent the rest of the semester online, learning tools for three-dimensional modeling, image processing with ENVI, and other tools.

Through a generous gift from Jeff Harris and Joyce Pratt, three students were able to extend the project into the summer. While they were still not allowed to be on campus, the students were able to take parts of the system to their homes where they continued building and improving the system. When campus was opened again in the fall, the students were able to reassemble the system and got some surprising results.

The Cary Graphic Arts Collection at the Rochester Institute of Technology has in its collection 50 leaves from the Otto Ege collection. The leaves make up a key component of the collection and are used in various curricular and research activities at RIT. Recently the freshmen's system has been used to discover that a manuscript from the Otto Ege collection is a palimpsest. A French Book of Hours, number 30, was discovered to have had French cursive removed, and the Book of Hours written as the overtext. Additionally, students identified and located other leaves from this Book of Hours and are continuing to look for palimpsests.

Senior Research Projects

Comparison of Methods to Detect Panels in Aerial Imagery

Juliana Fioravanti

Advised by Dr. Carl Salvaggio

Aerial imaging is the process of taking images from an elevated height, most commonly from a drone or aircraft. It is useful for many applications, including agricultural planning, inspection, and cartography. The data collection process typically yields a large set of images that need to be processed before evaluation. To aid in processing, calibration panels can be placed in the scene prior to image capture to serve as a known point of reference. Once these panels are identified in the images, they can then be used to calibrate the sensor and convert the images to an illumination invariant space; namely, reflectance. To save time and improve efficiency, the process of locating these panels can be automated. This project aims to compare methods of automatic panel detection by researching and improving upon previously implemented solutions. One of the methods has been proven successful with a high degree of accuracy.

Juliani is now a physicist / image scientist at Perspecta.

Characterization of Levitated Objects using Imaging Methods

Brian Hettiarachchi

Advised by Dr. Grover Swartzlander

Solar radiation pressure force modeling is a substantial area of research in the multidisciplinary study of solar sail technologies. Primarily, the challenge is to quantitatively and qualitatively understand light propulsion in a down-scaled, controlled environment. An apparatus that would allow this would further current research in radiation pressure applications. In this study, a prototype apparatus to levitate a low-mass object characterized by laminar airflow was built and tested. For the purpose of characterization, an algorithm was successfully implemented to mathematically model the two-dimensional motion of the object using threshold and centroid calculations. Two flow velocities were tested, one low and one high relative to each other. Theoretically, a high flow rate would yield a larger Reynolds Number and therefore lead to an unstable levitation. From the oscillation of the object, the spring stiffness was calculated to quantify the overall stability. The axis of oscillation was also calculated to study the overall behavior of the system. Ideally, the stiffness of the oscillator should approach zero to be considered stable. However, the stiffness was found to be on the order of 10–4N/m for both flow rates, which is insufficiently stable to conduct radiation pressure experiments. To achieve the stability required to move an object with radiation, new methods are proposed for the continuation of this research.

Brian is a camera engineering technician at Tesla.

Image Based Modeling of Complex Surfaces

Jared Luce

Advised by Dr. James Ferwerda

Light reflectometry has been an interesting topic for imaging scientists as it tackles ways to properly calculate the amount of light being reflected off of a surface. It is important for these scientists to recognize that every surface has two different types of reflectance properties: diffuse and specular. An ideal diffuse surface will re-radiate light equally in all directions, and an ideal specular surface will bounce all light equally in all directions, but the majority of surfaces are neither ideal diffuse surfaces nor ideal specular surfaces. It is then also important to recognize the amount of time and effort that would be necessary to calculate these values for every point along a surface, calling on the need for computational methods to record and calculate these values. With the values now accessible in an organized digital form, it becomes possible to take them and redevelop these surfaces using 3D modeling software that would allow this surface to share the same reflectance properties as its real version.

Optical Matched Filtering with Computer-Generated Holography

Gregory M. Nero

Advised by Dr. Roger Easton Jr.

Matched filtering is modeled using Fraunhofer binary cell-based computer-generated holography. Error diffusion is shown to have small improvements on hologram reconstruction performance but not on its matched filtering performance. Optical matched filtering with printed computer-generated holograms is discussed.

Greg is a PhD Student in optics at the University of Arizona.

No Reference RER Predictor

Adam Reitz

Advised by Dr. Derek Walvoord

The No Reference RER Predictor is a tool that uses Machine Learning coupled with Imaging Science to provide the user with an accurate sharpness metric known as RER. Knowing the RER of an image can provide insight to the performance of the imaging system taking the images. Previous methods used to derive the sharpness of an image come in two branches. The first, algorithms which produce a general sharpness metric which works over varying spatial content, and the second, algorithms which produce an accurate engineering metric, but only for specific spatial content that must be present in the scene. The No Reference RER Predictor aims to combine both these branches, and return an accurate RER metric over a wide variety of spatial content. Although the preliminary network produced only works on a chip size of 224 by 224, additional logic can be introduced to create a RER map across the whole image to view subtle changes in sharpness, or use a weighting system to return a single RER term for the larger image.

Adam is working at L3 Harris

Photogrammetric Analysis of NOx from Post-blast Fumes

Nelmy Robles-Serrano

Advised by Dr. Emmett Ientilucci

The use of modern industrial explosives can lead to the release of nitrous oxides (NOx), as a by-product, into the atmosphere. The formation of these fumes after a blast occurs is an unwanted characteristic of the blasting process and is dependent on a variety of variables. These nitrous oxides are hazardous and need to be monitored at all times. Austin Powder is looking for methods to quantify the total amounts of NOx in relation to the total amount of explosives used. The end goal of this research effort was to see if a photogrammetric techniques could be used to characterize the 3D nature of the clouds. This, in conjunction with concentration, can give insight into the total amount of nitrous oxide that has formed from the blast, if present. In addition, methods need to be able to differentiate the orange/yellow NOx clouds from the surrounding colored soil (not covered in this work). An automated structure from motion software tool was used in this research effort to accomplish 3D modeling of objects. Insights from modeling simple objects will be used to model 3D plumes. Our ultimate goal was to perform outdoor surrogate plume experiments with 3D reconstruction, but that final goal was not reached. Instead we evaluated a series of structure from motion software packages as applied to a variety of objects. We 3D reconstructed the objects and took note of the minimum number of cameras required for decent reconstruction. At the same time, we investigated how to determining the volume of a rectangular object.

Nelmy is working for L3 Harris

An Overview of Eye-Tracking Systems

D. James Ryckman

Advised by Dr. Gabriel Diaz

Eye-tracking is the process of measuring the location of one's gaze. It is an important tool for vision science, psychology, graphic design, medicine and more. This paper compares three different eye-tracking systems: the Dual-Purkinje Image (DPI) tracker, head-mounted video-based trackers, and the scleral search coil system. The DPI has very high spatial and temporal resolution, making it ideal for studies of small eye movements, though it can be difficult to acquire and use. Video trackers are far cheaper and can be worn by the subject, allowing for studies in visually-guided action or for consumer use. The scleral search coil has good spatial resolution and nearly unlimited temporal resolution, and is used most often in biological or medical studies, but its invasive nature can cause difficulties for experimenters and subjects.

James is a Systems Engineer at Aeroptic LLC

Imaging Classification and Analysis of CD8+T-Cells Motility and Movement

Ian Smith

Advised by Dr. Guoyu Lu

Medical imaging-based research requires a new scope of data analysis tools in today's research world, and this work aims to implement new metrics to better understand CD8+T-cell responses to Influenza virus infection. The goal is to incorporate both imaging science concepts and previous research in the biology field to generate a program that tracks and compares cells as they move along 2D and 3D surfaces. Intensity thresholding, blob/object detection, morphological filtering, and feature detection are the key concepts that can enhance the current state of analyzing microscopy-based images. Continuing with these concepts, features of the tissue such as cells and glands become more distinguishable, allowing for different components to be quantified. By defining metrics such as cellular positioning, area, and their centroid in conjunction with imaging techniques, mechanical physics and cellular classification are the resultant outputs. This image analysis tool will be transformed into a graphical user interface (GUI) that will represent the analytical capabilities, while preserving both the integrity of the data and enhancing the ability to view and present these findings. Moreover, a GUI will provide users a friendly platform for analysis that can be used by any scientists as a tool to perform reliable image classification and quantification analysis with ease.

Low-Voltage Scanning Electron Microscope Image Restoration Using Interpolated PSF Deconvolution

Leonard Wilkinson

Advised by Mr. Rich Hailstone

The practice of point-spread function (PSF) deconvolution has been demonstrated as a valid method for the reduction of blur and recovery of sharp features in images produced using a scanning electron microscope (SEM). The parameter space of this practice, however, is highly dimensional. Most studies conducted have focused on the restoration of SEM data collected under varied accelerating voltages with the intention of modeling the effects of this variation, as well as the variation of other parameters, on the resulting PSF of the system. In this study, variation of multiple independent parameters while approaching low-voltage-case data collection is used to quantify the manner in which this system PSF changes as operating conditions are modified. Analysis of the data collected is then used to generate predictive models of these effects, allowing for the performance of PSF-based restoration on images for which calibration data has not been directly collected. This novel method of restoration is designed to save time and allow operating conditions to be varied without losing calibration.

Lenny is a physicist and imaging scientist at Perspecta

Using a Low-Frequency EPR Mobile Universal Surface Explorer (MOUSE) to Image Nonuniform Paramagnetic

Haley E. Wiskoski

Advised by Dr. Joseph P. Hornak

Artists and creators throughout history have used many techniques from mixing, to layering, to creating patterns with various materials. This study aims to explore how the LFEPR mobile universal surface explorer (MOUSE) can measure and model the spatial distribution of paramagnetic pigments in a sample. The proposed methods explore two main capabilities of the LFEPR MOUSE: layer/depth analysis and modeling, as well as EPR imaging of paramagnetic materials. The results of this study can be used in fields such as historical artifact dating, medical/biological imaging, or even engineering, to explore information of a sample that lies beneath what is readily apparent to an observer.

Haley is a graduate student in optics at the University of Arizona

Projection Mapping of Cultural Heritage Objects

Valerie Yost

Advised by Dr. James Ferwerda

Cultural heritage objects are artifacts from the past that are used to understand history. Projection mapping and related technologies provide a set of tools that enable objects to be transformed into realistic representations of other objects. In this paper we will survey the technologies and techniques of projection mapping as applied to the representation and visualization of cultural heritage objects.

Valerie is an image analyst at Invicro, A Konica Minolta Company

Academics

Graduate Program Update

Graduate Program Update

by Dr. Charles Bachmann, Graduate Program Coordinator

The graduate program in Imaging Science is a unique environment for research and education in this important cross-disciplinary field. Each year we draw students from a wide range of STEM disciplines and from diverse backgrounds both within the US and internationally. This diversity is at the core of our program and allows our students to thrive in our interdisciplinary learning and research environment, developing into well-prepared professionals who are widely sought after in industry and government laboratories as well as academic centers and not-for-profit institutions. Below are details of the many developments within the graduate program this past year. This highlights developments such as curricular changes as well as a wide variety of outstanding student achievements.

Graduate Program Faculty

As of the end of the 2019-20 academic year there were a 56 members of the CIS Graduate Program Faculty. Among our faculty, 19 are tenured, or tenure-track, with the Center as their primary appointment, while another 15 have a primary appointment in one of thirteen other departments centers, programs or laboratories with which the Center is affiliated. Also, the Center is the home to 9 Research Faculty. There are thirteen Program Allied Faculty who hold positions at other organizations outside of RIT.

Curriculum Development

This year marked the second year of a newly implemented structure for the Graduate Laboratory course, normally taken by our first-year graduate students. In the past the course had been offered as a year-long project-based course with one course credit for each of the two semesters. The course was designed to give students an early experience in research alongside the core courses normally taken in first year. Recently, however, the faculty decided that providing students with a practical skills-based course offered only in the fall semester would better suit the needs of incoming students and overall would better prepare them for success in our program. Forgoing the early research experience was a reasonable compromise, especially since most graduate students have joined a research group by the end of their first year in our program. Accordingly, this year the Graduate Laboratory course focused on the development of skills such as Python programming, a refresher of the advanced mathematics needed in our Imaging Science curriculum, as well as background in Noise and Probability that the faculty felt would also be helpful prior to taking the formal core course in that topic area. The new Graduate Laboratory is a two-credit course, which will be offered each fall semester.

This year we provided our first-year graduate class with a "re-orientation" led by our Center Director and Graduate Program Coordinator just prior to the start of the second semester. The goal of the re-orientation is help students more smoothly transition from a workload dominated by coursework to one more heavily focused on research. This is the fourth year that we have provided a "re-orientation" to our first-year graduate student cohort, and having seen the importance of this process to student success, we have now made it a permanent part of the schedule.

Other curricular changes this year included a new graduate elective Special Topics course in Robot Vision taught by Dr. Guoyu Lu, who joined the CIS faculty in 2017. In addition, separate courses offered in Remote Sensing Systems and Image Analysis have now been merged into a single cross listed course (IMGS-540/640), and another course in Performance Modeling and Characterization of Remote Sensing Systems (IMGS-765) has been moved to the fall semester to better support the typical needs of our students. In the coming year, we will also be offering a new graduate special topics course related to synthetic aperture radar (SAR) imaging.

Graduate Student Body

At the beginning of the 2019-20 academic year, there were 108 graduate students in Imaging Science. Our student population is highly diverse and the incoming graduate student class included international students from 5 countries: 3 from China, 1 from India, 2 from Bangladesh, 1 from Peru, and 12 from the United States. In total, our incoming graduate student class consisted of 19 students. Of these, 5 students are pursuing the MS degree, with 1 being part-time students, while 14 students are pursing the Ph.D. degree.

Student Awards

Our students continue to receive a significant recognition for their accomplishments in a number of widely recognized professional settings. Student names are in **bold**.

Greg Badura and Charles M Bachmann, "Assessing Effects of Azimuthally Oriented Roughness on Directional Reflectance of Sand," *IEEE Geoscience and Remote Sensing Society, 2020 JSTARS Prize Paper Award,* Sept 2020, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, 12(3), pp. 1012-1025, 2019.

Tyler L. Hayes and Christopher Kanan, "Lifelong machine learning with deep streaming linear discriminant analysis," Best Paper Award at the *CVPR-2020 Workshop on Continual Learning in Computer Vision*, in Conference on Computer Vision and Pattern Recognition Workshops (CVPR-W), 2020.

Rinaldo Izzo, "An initial analysis of real-time sUAS-based detection of grapevine water status in the Finger Lakes wine country of upstate New York," *Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping conference at the SPIE DCS Symposium*, Best Paper Award.

Anjali K Jogeshwar and Jeff Pelz, "Hand localization for hand grasp analysis in natural tasks", *Western New York Image and Signal Processing Workshop*, Best poster award, 2019

Rakshit Kothari, Manoj Acharya, Aayush Chaudary, RITNet won first place in the *Facebook Research OpenEDS 2019* competition.

Yawen Lu, Yuxing Wang, and **Devarth Parikh**, Third place in the *SICK Inc. TiM$10K Challenge*, 2020.

Mahshad Mahdavi, R Zanibbi, H Mouchère, C Viard-Gaudin, U Garain *ICDAR 2019 CROHME+ TFD:* Competition on recognition of handwritten mathematical expressions and typeset formula detection.

Emily Myers, "Monitoring Crop Growth Using UAS and Satellite Imagery" *2019 IEEE GRSS STRATUS Workshop*, Student paper award.

Kamal Rana, "Integrating Climate Network Analysis with Machine Learning to Predict South Asian Monsoon," *RIT Graduate Showcase,* Best Oral Presentation.

Benjamin Roth, "Broadleaf Bidirectional Reflectance Function (BRDF) Measurements and Modeling," *RIT Graduate Showcase* Best Presentation, 2019.

Biswa Swain, C. Dorrer, S. DeFisher, and J. Qiao, "High-Dynamic Range, High-Resolution Freeform Metrology with Optical Differentiation Wavefront Sensing," *OSA Student Paper Award,* 2020.

Student Publications and Presentations

Presentation and publication of scholarly research remains a cornerstone of the CIS graduate curriculum, and this year was no exception. Students are widely represented in the scholarly output of CIS overall, and for almost all publications that emanate from CIS, a student is either the lead author or a co-author of the publication. Below we highlight some of these accomplishments by providing a list of articles published in refereed journals as well as in proceedings of professional conferences and symposia.

Selected Journal Articles with Graduate Student Authors

A. Chaudhary and J. Pelz, "Motion tracking of iris features to detect small eye movements," *Journal of Eye Movement Research*, 12(6), April 5, 2019. https://doi.org/10.16910/jemr.12.6.4

S. Dangi, C. A. Linte, and Z. Yaniv, "A distance map regularized CNN for cardiac cine MR image segmentation," *Medical Physics*, vol. 46, no. 12, pp. 5637–5651, October 31, 2019. doi: 547, 10.1002/mp.13853

R. Ducay and D. W. Messinger, "Radiometric assessment of four pan-sharpening algorithms as applied to hyperspectral imagery," *Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXVI*, May 19, 2020, doi: 10.1117/12.2558741

R. S. Eon, C. M. Bachmann, **C. S. Lapszynski, A. C. Tyler, S. Goldsmith**, "Retrieval of Sediment Fill Factor in a Salt Panne from Multi-View Hyperspectral Imagery," *Remote Sensing* 12,3:422, 2020. https://doi.org/10.3390/rs12030422.

C. Ge, H. N. Cheng, M. J. Miri, R. K. Hailstone, J. B. Francis, S. M. Demyttenaere, and **N. A. Alharbi**, "Preparation and evaluation of composites containing polypropylene and cotton gin trash," *Journal of Applied Polymer Science*, vol. 137, no. 38, p. 49151, March 2, 2020, doi: 10.1002/app.49151

A. Gerace, T. Kleynhans, **R. Eon**, and M. Montanaro, "Towards an Operational, Split Window-Derived Surface Temperature Product for the Thermal Infrared Sensors Onboard Landsat 8 and 9," *Remote Sensing*, vol. 12, no. 2, p. 224, January 9, 2020. doi: 10.3390/rs12020224

S.B. Goldsmith, R.S. Eon, C.S. Lapszynski, G.P. Badura, D.T. Osgood, C.M. Bachmann, A.C. Tyler, "Assessing Salt Marsh Vulnerability using High-Resolution Hyperspectral Imagery," *Remote Sensing*, 12(18), 2938, 2020. https://doi.org/10.3390/rs12182938.

G. Jalalahmadi, M. Helguera, and C. A. Linte, "A machine leaning approach for abdominal aortic aneurysm severity assessment using geometric, biomechanical, and patient-specific historical clinical features," *Medical Imaging 2020: Biomedical Applications in Molecular, Structural, and Functional Imaging,* February 28, 2020, doi: 10.1117/12.2549277

K. Jnawali, B. Chinni, V. Dogra, and N. Rao, "Automatic cancer tissue detection using multispectral photoacoustic imaging," *International Journal of Computer Assisted Radiology and Surgery*, vol. 15, no. 2, pp. 309–320, December 21, 2019. doi: 10.1007/s11548-019-02101-1

B.G. Mamaghani, C. Salvaggio, "Comparative study of panel and panelless-based reflectance conversion techniques for agricultural remote sensing," *American Journal of Agricultural Science*, 6, 4, pp. 40-58, November 12, 2019.

B. Mamaghani, M. G. Saunders, and C. Salvaggio, "Inherent Reflectance Variability of Vegetation," *Agriculture*, vol. 9, no. 11, p. 246, November 16, 2019, doi: 10.3390/agriculture9110246

J. Miller, A. Gerace, **R. Eon**, M. Montanaro, R. Kremens, and J. Wehle, "Low-Cost Radiometer for Landsat Land Surface Temperature Validation," *Remote Sensing*, vol. 12, no. 3, p. 416, January 28, 2020. doi:10.3390/rs12030416

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*, vol. 11, no. 21, p. 2558, October 31, 2019, doi: 10.3390/rs11212558

K. Oram, Z. Ninkov, **A. Irwin, D. Vorobiev**, M. Carts, "Further investigation of the effects of total ionizing dose on digital micromirror devices," *Emerging Digital Micromirror Device Based Systems and Applications XII* 11294, Feb. 28, 2020, https://doi.org/10.1117/12.2549104

B. D. Roth, M. G. Saunders, C. M. Bachmann, J. van Aardt, 2020. “On Leaf BRDF Estimates and Their Fits to Microfacet Models,” *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, 13(1): 1761-1771, April 22, 2020. https://doi.org/10.1109/JSTARS.2020.2988428.

E.B. Andreas Savakis, **N. Nagananda**, J. P. Kerekes, E.J. Ientilucci, “Change Detection in Satellite Imagery with Region Proposal Networks,” *DSIAC Journal* 6 (4), 22-28, Fall 2019.

B. R. Swain, C. Dorrer, and J. Qiao, “High-performance optical differentiation wavefront sensing towards freeform metrology,” *Optics Express*, vol. 27, no. 25, p. 36297, November 26, 2019, doi: 10.1364/oe.27.036297

A. M. Taufique, B. Minnehan, and A. Savakis, “Benchmarking Deep Trackers on Aerial Videos,” *Sensors*, vol. 20, no. 2, p. 547, January 19, 2020, doi: 10.3390/s20020547

Selected Conference Publications with Graduate Student Authors

M. Acharya, K. Kafle, and C. Kanan, “TallyQA: Answering Complex Counting Questions,” *Proceedings of the AAAI Conference on Artificial Intelligence*, vol. 33, pp. 8076–8084, July 17, 2019, doi: 10.1609/aaai.v33i01.33018076

A. Borkar, **S. Sinha**, N. Dhengre, B. Chinni, V. Dogra, and N. Rao, “Diagnosis of Prostate Cancer with Support Vector Machine Using Multiwavelength Photoacoustic Images,” *Proceedings of 3rd International Conference on Computer Vision and Image Processing*, pp. 247–254, 2019. November, 1, 2019, doi: 10.1007/978-981-32-9088-4_21

A. K. Chaudhary, R. Kothari, M. Acharya, S. Dangi, N. Nair, R. Bailey, C. Kanan, G. Diaz, and J. B. Pelz, “RITnet: Real-time Semantic Segmentation of the Eye for Gaze Tracking,” *2019 IEEE/CVF International Conference on Computer Vision Workshop (ICCVW)*, October 2019, doi: 10.1109/iccvw.2019.00568

Z. Cui and J. Kerekes, “Potential of Red Edge Spectral Bands in Future Landsat Satellites on Agroecosystem Canopy Chlorophyll Content Retrieval,” *IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium*, 2019. July 2019, doi: 10.1109/igarss.2019.8898783

A. Hassanzadeh, S. Murphy, S. Pethybridge, J.A. van Aardt, “Yield Modelling and Growth Stage Classification of Snap-bean Based on Hyperspectral Sensing: A Greenhouse Study,” *AGU, Annual Symposium*, AGU, San Francisco, CA, December 9-13, 2019

Y. Lu, S. Kourian, C. Salvaggio, C. Xu, and G. Lu, “Single Image 3D Vehicle Pose Estimation for Augmented Reality,” *2019 IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, November 13, 2019, doi: 10.1109/globalsip45357.2019.8969201

Y. Lu, M. Sarkis, and G. Lu, “Multi-Task Learning for Single Image Depth Estimation and Segmentation Based on Unsupervised Network,” *2020 IEEE International Conference on Robotics and Automation (ICRA)*, May 2020, doi: 10.1109/icra40945.2020.9196723

M. Maali Amiri, K. Binaee, and J. Ferwerda, “A Comparison of Colorimetric Performance of Oculus and HTC Virtual Reality Headsets,” *Frameless*, vol. 1, no. 1, pp. 1–10, 2019. December 15, 2019, doi: 10.14448/frameless.01.005

M. Mahdavi, L. Sun, and R. Zanibbi, “Visual Parsing with Query-Driven Global Graph Attention (QD-GGA): Preliminary Results for Handwritten Math Formula Recognition,” *2020 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, June 2020. doi: 10.1109/cvprw50498.2020.00293

M. Massoud, J. Francis, S. Demyttenaere, **N. Alharbi,** C. Ge, R.K.Hailstone, H.N. Cheng, “Preparation and Evaluation of Composites Comprising Polypropylene and Cotton Gin Trash,” *258th ACS National Meeting & Exposition*, pp. AGFD-0163, San Diego, California, United States, August 01, 2019

Z. Mulhollan, A. Rangnekar, T. Bauch, M. J. Hoffman, and A. Vodacek, “Calibrated Vehicle Paint Signatures for Simulating Hyperspectral Imagery,” *2020 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, June 14-19, 2020. doi:10.1109/cvprw50498.2020.00063

N. Nair, **A.K. Chaudhary, R.S. Kothari**, G.J. Diaz, J.B. Pelz, R. Bailey “RIT-Eyes: realistically rendered eye images for eye-

tracking applications," *ACM Symposium on Eye Tracking Research and Applications (ETRA '20) Adjunct: ACM Symposium on Eye Tracking Research and Applications*, June 2020, Article No.: 7, pp. 1–3 https://doi.org/10.1145/3379157.3391990

S. Padhye; J.A. Ferwerda, D.W. Messinger," Digital Modeling of Cultural Heritage Objects," The Frameless Journal, 4th Frameless Symposium,vol. 2, no. 1, November 2019

R. Roady, T. L. Hayes, H. Vaidya, and C. Kanan, "Stream-51: Streaming Classification and Novelty Detection from Videos," *2020 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, June 2020, doi: 10.1109/cvprw50498.2020.00122

B. Roth, C.M. Bachmann, J.A. van Aardt, "Deciduous Broad Leaf Bidirectional Scattering Distribution Function (BSDF): Measurements, Modeling, and Effects on Leaf Area Index (LAI) for Forest Ecological Assessments," *Silvilaser, Annual Conference*, Iguazu Falls, Brazil, October 8-10, 2019

A. Rouzbeh-Kargar, R. Mackenzie, J.A. van Aardt, "Assessment of Above-ground Root Growth and Surface Elevation Changes In Mangrove Forests Using a Rapid-Scan Terrestrial Laser Scanner," *AGU Annual Symposium*, San Francisco, CA, December 9-13, 2019

A. M. Taufique, A. Savakis, and J. Leckenby, "Automatic Quantification of Facial Asymmetry Using Facial Landmarks," *2019 IEEE Western New York Image and Signal Processing Workshop (WNYISPW),* October 2019. doi:10.1109/wnyipw.2019.8923078

R. R. Upendra, S. Dangi, and C. A. Linte, "Automated segmentation of cardiac chambers from cine cardiac MRI using an adversarial network architecture," *Medical Imaging 2020: Image-Guided Procedures, Robotic Interventions, and Modeling,* March 16, 2020. doi: 10.1117/12.2550656

Certified Graduates

MS Graduates

Grad Name	Thesis Title	Advisor	Current Job
Michael Grady Saunders	Randomizable phenology-dependent corn canopy for simulated remote sensing of agricultural scenes	Jan van Aardt	Assistant Research Scientist Center for Imaging Science, RIT
Zhongchao Qian	Deep Convolutional Networks without Learning the Classifier Layer	Christopher Kanan	Research Programmer, Scripps Research
Matthew Helvey	Application of Thermal and Ultraviolet Sensors in Remote Sensing of Upland Ducks	Jan van Aardt, Susan Ellis-Felege, Carl Salvaggio	Officer, United States Space Force
Ethan Hughes	Spatially Explicit Snap Bean Flowering and Disease Prediction Using Imaging Spectroscopy from Unmanned Aerial Systems	Jan van Aardt	Satellite Applications and Research Scientist, I. M. Systems Group Inc. (IMSG)
Jason Slover	Synthetic Aperture Radar simulation by Electro Optical to SAR Transformationusing Generative Adversarial Network	Michael Gartley	Officer, United States Air Force
Devarth Parikh	Gaze Estimation Based on Multi-view Geometric Neural Networks	Guoyu Lu	Research Engineer, 3D Computer Vision, Ford Motor Company

PhD Graduates

Grad Name	Dissertation Title	Advisor Name	Current Job
Viraj Adduru	Automated brain segmentation methods for clinical quality MRI and CT images	Stefi Baum	Applied Researcher, Expedia Group
Di Bai	A Hyperspectral Image Classification Approach to Pigment Mapping of Historical Artifacts Using Deep Learning Methods	David Messinger	Hardware Engineer, Google
Shusil Dangi	Computational Methods for Segmentation of Multi-Modal Multi-Dimensional Cardiac Images	Cristian Linte	Senior Engineer, Qualcomm
Rehman Eon	The Characterization of Earth Sediments using Radiative Transfer Models from Directional Hyperspectral Reflectance	Charles Bachmann	Assistant Research Scientist Center for Imaging Science, RIT
Alex Fafard	Clearing the Clouds: Extracting 3D information from amongst the noise	Jan van Aardt	Imaging Scientist, L3 Harris
Utsav Gewali	Machine Learning for Robust Understanding of Scene Materials in Hyperspectral Images	Eli Saber	Image Processing/ Computer Vision, Apple
Sanghui Han	Utility Analysis for Optimizing Compact Adaptive Spectral Imaging Systems for Subpixel Target Detection Applications	John Kerekes	Radar System Engineer Resonant Sciences, LLC
Kamal Jnawali	Automatic Cancer Tissue Detection Using Multispectral Photoacoustic Imaging	Navalgund Rao	Senior Research Engineer, Samsung Electronics
Kushal Kafle	Computational Methods for Segmentation of Multi-Modal Multi-Dimensional Cardiac Images	Christopher Kanan	Research Scientist, Adobe
Michael Kucer	Representations and representation learning for image aesthetics prediction and image enhancement	David Messinger	Post-doc Researcher, Los Alamos National Lab
Yilong Liang	Object Detection in High Resolution Aerial Images and Hyperspectral Remote Sensing Images	Eli Saber	Computer Vision Software Engineer, Apple
Yansong Liu	Semantic Segmentation of Multi-sensor Remote Sensing Images	Eli Saber	Computer Vision/Machine Learning Engineer, Apple
Baabak Mamaghani	An Analysis of the Radiometric Quality of Small Unmanned Aircraft System Imagery	Carl Salvaggio	KBR, Inc
Sankaranarayanan Piramanayagam	Segmentation and Classification of Multimodal Imagery	Eli Saber	Senior Appied Research Engineer, Sony Electronics
Jacob Wirth	Point Spread Function and Modulation Transfer Function Engineering	Grover Swartzlander	Senior Research Scientist, Lockheed Martin

Research

Select Faculty Research

Charles Bachmann

GRIT (Goniometer of RIT) Lab

Research

Hyperspectral Video Imaging and Mapping of Littoral Conditions

Principal Investigator: Dr. Charles Bachmann

Research Team: Rehman Eon (PhD Student; Ph.D., 2019), Christopher Lapszynski (PhD Student), Gregory Badura (Ph.D., 2018)

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 (Figure 1). 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* (*J. Imaging* 2019, 5(1)). 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.

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 (Figure 1) to directly estimate the sediment filling factor (density). 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 retrieval methodology to retrieve sediment water content using the DIRS unmanned aerials systems (UAS). This work uses a new radiative transfer model designed specifically to describe sediment pore water. Some of our more recently published laboratory analyses complement our field validation studies and have used our GRIT-T hyperspectral goniometer system (Figure 1) 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

Figure 1. Field validation of models for retrieval of sediment geophysical properties using multi-temporal and multi-view 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.

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.

Improving Estimates of Salt Marsh Resilience and Coastal Blue Carbon

Principal Investigator: Dr. Christy Tyler (Environmental Sciences Program), Dr. Charles Bachmann (CIS)

Research Team: Rehman Eon (CIS PhD Student; Ph.D., 2019), Christopher Lapszynski (CIS PhD Student), Sarah Goldsmith (Environmental Sciences, MS Student, MS 2020), Avery Miller (Environmental Sciences, MS Student)

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.

Using hyperspectral imagery collected of a marsh chronosequence collected by our team using our mast-mounted hyperspectral system 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 2). These initial results were published in a Special Issue of the journal Remote Sensing with examples provided in Figure 2 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. The latter studies of salt marsh vegetation exposed 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 by being able 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, particularly for 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 2). 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*.

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.

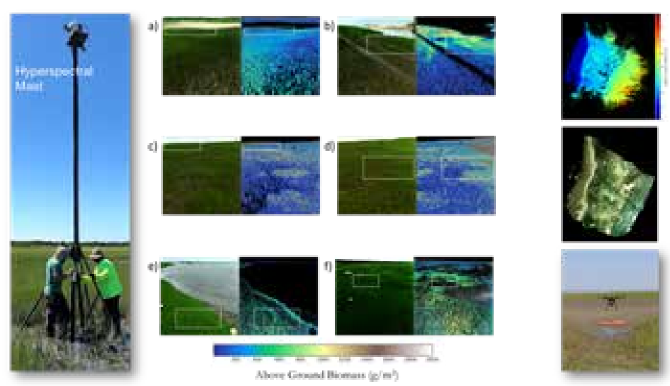


Figure 2. This project is focused on quantitative estimate of "Blue Carbon" storage. Using our mast-mounted hyperspectral imaging system (left), we have developed high-resolution models of salt marsh above-ground biomass (center, showing pairs of hyperspectral scenes and biomass retrievals). We have 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.

Publications

S.E. Rehman S. Eon, **C.M. Bachmann**, C.S. Lapszynski, A.C. Tyler, S. Goldsmith, “Retrieval of Sediment Filling Factor in a Salt Panne from Multi-View Hyperspectral Imagery,” *Remote Sens.* 2020, 12(3), 422; https://doi.org/10.3390/rs12030422

G. Badura, **C. M. Bachmann**, J. Harms and A. Abelev, “Observed Relationship Between BRF Spectral-Continuum Variance and Macroscopic Roughness of Clay Sediments,” in *IEEE Transactions on Geoscience and Remote Sensing*, vol. 57, no. 9, pp. 6726-6740, Sept. 2019, doi: 10.1109/TGRS.2019.2908170.

B. D. Roth, M. G. Saunders, **C. M. Bachmann**, and J. A. van Aardt, “On Leaf BRDF Estimates and Their Fit to Microfacet Models,” in *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 13, pp. 1761-1771, 2020, doi: 10.1109/JSTARS.2020.2988428.

Grants

Bachmann, Charles, “Hyperspectral Video Imaging Assessment and Mapping of Littoral Conditions,” NGA, $148,204.

Gabriel Diaz

PerForm (Perception for Movement) Lab

Research

Despite COVID-related adversity, the PerForM Lab run by Director Gabriel J. Diaz has had a very productive 2020 academic year. Research in the PerForM Lab is focused at the intersection of neuroscience, psychology, computer science, and imaging science, with the goal of improving understanding of how movements of the eyes, head, hands, and body are coordinated during the performance of visually guided actions. In 2020, the laboratory secured two substantial grants consistent with these aims: a grant from the National Institutes of Health for the development of novel methods for the rehabilitation of vision following loss due to stroke, and from Facebook Reality Labs for the development of novel algorithms related to eye tracking in mobile and virtual environments. The research that will be supported by these awards is described below.

The year has also been a positive one for our graduate students, who continue to demonstrate the value of RIT's doctoral degree in Imaging Science. Rakshit Kothari has just returned from a coop with Nvidia's research division where he worked on machine learning solutions for improved eye tracking. Later this year, Catherine Fromm will begin her co-op with Facebook Reality Labs' research team in advanced displays. These accomplishments bode well for the future of the department, as does the arrival of new graduate student Arianna Giguirre, who recently graduated from the University of Maine with a BS in Physics and Mathematics. Onwards and upwards!

The newly awarded NIH R15 grant, Development and Assessment of Virtual Reality Paradigms for Gaze Contingent Visual Rehabilitation, is intended to support primarily undergraduate research teams. Consistent with these goals, this project currently supports two graduate students and three undergraduate students in active research in the development of new paradigms for non-invasive visual restitution therapy following vision loss due to stroke. Stroke-induced occipital damage is an increasingly prevalent, debilitating cause of partial blindness, which afflicts about 1% of the population over age 50. Until recently, this condition was considered permanent. However, over the last 10 years, the Huxlin lab at the University of Rochester has pioneered a training method to recover a range of visual abilities in previously blind fields. Our work is conducted in collaboration with Dr. Huxlin, and seeks to build upon her substantial efforts.

The novelty of our proposed work involves transitioning the paradigms from a desktop task environment that must be completed under experimenter supervision to a virtual reality task environment that can be used at home, and in the absence of experimenter supervision. The subject is asked to fixate at a point on screen as they are presented with a simple visual stimulus in the periphery. Their task is either to make a simple perceptual judgment about the stimulus (e.g. to indicate via button-press that motion is towards the top-left), or to break fixation and use the VR controller to make a very rapid movement through the moving stimulus (e.g. in the perceived direction of motion). Tasks involve ten consecutive days of visual training (30 minutes per session) that are book-ended by pre-and post-tests of visual sensitivity. Comparison of pre and post-tests allow us to test the effectiveness of the intervening training task under question in terms of the rate and magnitude of the change in sensitivity. This work is still in the exploratory stage,, and not yet suitable for clinical use.

The newly awarded grant from Facebook Reality Labs "Improved Semantic Segmentation with Natural Gaze Dynamics," will support research in the area of machine-learning algorithms for gaze tracking in mobile and virtual environments. Our interest and expertise in the area of eye

tracker algorithm development was first demonstrated in 2019, when a collaborative group of CIS graduate students working in the PerForm Lab, MVRL, and K-Labs won first place in the Facebook OpenEDS challenge. Since then, the PerForM Lab has published steadily in this area. Most recently, EllSeg: An Ellipse Segmentation Framework for Robust GazeTracking has been accepted for publication at IEEE-VR 2021, and authors include Rakshit S. Kothari , Aayush K. Chaudhary , Reynold J. Bailey, Jeff B. Pelz and Gabriel J. Diaz. In this manuscript, we detail a novel method for segmenting/identifying pixels belonging to the pupil present in infrared imagery of the human eye. Identification of the pupil, and its centroid, is a critical step for many contemporary eye tracking algorithms, and one in which even a few pixels of inaccuracy can inflate to many degrees of inaccuracy in the final estimation of gaze direction. This manuscript shows that our novel algorithm outperforms others in its accuracy and robustness in the presence of occlusion of the pupil by the surrounding skin, or intervening optics (e.g. glasses).

The rendering of near-eye images for eye-tracking applications has also recently been published in the ACM Symposium for the Society for Applied Perception, in September, 2020. Our efforts to create new algorithms for eye tracking rely upon training models with supervised machine learning methods. Consequently, training requires a large corpus of eye images that have been carefully segmented, at the pixel-level, into constituent components (e.g. pupil, iris, sclera, and surrounding skin). Because these images take a considerable amount of time to label by hand, we have been developing new methods for the use of computer graphical pipelines for the automated generation of imagery that is representative in terms of skin tones, ages, cultural backgrounds, and gender.

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R. Kothari, Z. Yang, C. Kanan, R. Bailey, J.B. Pelz, **G.J. Diaz**, “Gaze-in-wild: A dataset for studying eye and head coordination in everyday activities.” *Scientific Reports,* vol. 10, no. 2539 (Feb. 13, 2020). https://doi.org/10.1038/s41598-020-59251-5

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K. Binaee, R.S. Kothari, **G.J. Diaz,** “Closed-loop vs predictive control characterized by inverse reinforcement learning of visuomotor behavior during target interception,“ *Journal of Vision*, Sept. 2019, Vol.19, 276a. doi:https://doi.org/10.1167/19.10.276a.

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C. Fromm, K. Huxlin, **G.J. Diaz**, “Using Virtual Reality with Integrated Eye Tracking for Visual Rehabilitation,” *Frameless*, Vol. 1: Iss. 1 , Article 16, doi: 10.14448/Frameless.01.003

Grants

Diaz, Gabriel, “Improved Semantic Segmentation with Natural Gaze Dynamics,” Facebook

Diaz, Gabriel, “Development and Assessment of Virtual Reality Paradigms for Gaze Contingent Visual Rehabilitation”, NIH

James Ferwerda

Visual Imaging Technologies Lab

Research

The focus of research in the Visual Imaging Technologies Lab is on two related themes. First, we are working to understand how images serve as realistic visual representations of real-world objects. We do this by conducting psychophysical experiments on visual perception, and building computational models based on these experiments that quantify the relations between image properties and our visual experiences. Second, we use these models to develop advanced image capture and display systems that seek to make images that are indistinguishable from the real world.

To advance the first theme Professor Ferwerda spent the summer of 2019 visiting and collaborating with colleagues at the Technical University of Delft, The Netherlands (Pont, Elkhuizen), and the University of Giessen, Germany (Cheeseman, Fleming, Dorschner). The latter interaction resulted in two projects.

Lab Members

Prof. James Ferwerda, P.I.
Snehal Padhye, Ph.D. student
Morteza Maali Amiri, Ph.D. student
Kamran Binaee, Ph.D. student
Valerie Yost, senior, B.S. program
Jared Luce, senior, B.S. program
Charles Brinsfield, sophomore, B.S. program (summer REU Emerson Fellowship)

Scaling and Discriminability of Perceived Gloss

Cheeseman, Fleming, Ferwerda

While much attention has been given to understanding biases in gloss perception (e.g., changes in perceived reflectance as a function of lighting, shape, viewpoint and other factors), here we investigated sensitivity to changes in surface reflectance. Stimuli consisted of renderings of glossy objects under natural illumination. Using Maximum Likelihood Difference Scaling, we created a perceptual scaling of the specular reflectance parameter of the Ward reflectance model. Then, using the Method of Constant Stimuli and a standard 2AFC procedure, we obtained psychometric functions for gloss discrimination across a range of reflectance values derived from the perceptual scale. Both methods demonstrate that discriminability is significantly diminished at high levels of specular reflectance, suggesting that gloss sensitivity depends on the magnitude of change in the image produced by different reflectance values.

Visual Perception of Surface Properties Through Direct Manipulation

Padhye, Ferwerda, Phillips, Dorschner

Vision is a component of a perceptual system whose function is to provide information in support of purposeful behavior. In this project we studied the perceptual system that supports the visual perception of surface properties through manipulation. In a series of trials, we gave observers the task of inspecting computer-graphics renderings of flat glossy surfaces and determining if there are any dents in the surfaces. The surfaces were displayed on a tangible display system consisting of an Apple iPad running custom software that rendered the surface in the plane of the screen, and allowed observers to directly interact with the surface by tilting and rotating the device. The results of our studies show patterns of manipulation that are diagnostic with respect to the task. These studies suggest the presence of an active sensori-motor perceptual system involved in the perception of surface properties, and provide a novel method for its study

Screenshot of the "dent" stimulus used in our "Perception of surface properties through direct manipulation" experiments.

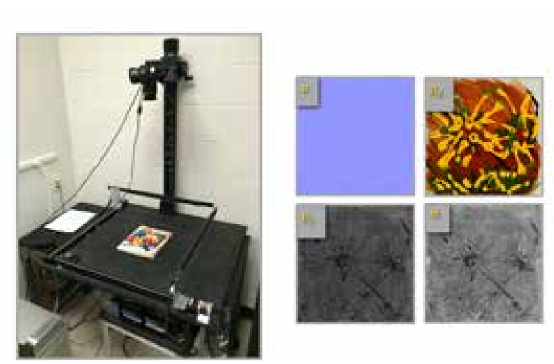
using tangible display systems.

To advance the second theme Professor Ferwerda advised graduate and undergraduate students in the Imaging Science program. This resulted in four projects.

Digital Modeling of Cultural Heritage Objects

Padhye, Ferwerda, Messinger

The objects that people create are a rich source of information about human culture. Objects like pottery, textiles, sculptures, and paintings, provide deep insight into the lives of the people who created them. Due to the physical nature of these objects, society is at risk of losing the cultural heritage they represent. The goal of this project is to develop technology to enable the digital preservation of cultural heritage objects, by creating rich digital models that accurately represent the three-dimensional shapes and textures of the objects, and the physical reflectance properties of their materials. To support this effort, we are developing novel 3D image-based surface capture systems. This project is highly synergistic with our related work to develop "tangible display systems" that enable natural interaction with virtual objects.



Linear light reflectometer and surface parameter maps developed for our "Digital modeling of cultural heritage" project.

A Comparison of Colorimetric Performance of Oculus and HTC Virtual Reality Headsets

Amiri, Binaee, Ferwerda

Colorimetric characterizations of the Oculus and HTC virtual reality headsets were examined in this work. First, a colorimeter was used to measure the values of the primary ramps in a darkened and controlled environment. It was observed that the two headsets behave similarly, with the HTC outputting an overall higher level of luminance, and having more consistent right and left displays. Subsequently, a weighted regression and a tradition linear model were used to characterize the devices. A desktop LCD display was also measured and characterized. The results for the headsets and LCD were compared to see how accurate the colorimetry of the headsets was. The results show that the headsets were not able to follow either model and therefore, it is recommended that caution should be exercised when using these commercial VR headsets for colorimetry related experiments.

Projection mapping of cultural heritage objects

Yost, Ferwerda

The goal of this project is to create a projection mapping system designed for simulating cultural heritage objects. Reflective 2D and 3D objects are projected onto and transformed into cultural heritage objects with gloss and texture. An observer tracking system makes the objects more realistic so the gloss and texture changes as the observer changes viewing angles.

PhantoView: Hands-on Interaction with Virtual Objects

Brinsfield, Ferwerda

With the advancement of mobile display technology and digital scanning methods, means to accurately present recorded models to observers remains to be seen. The PhantoView aims to recreate intuitive interaction with digital objects using gyroscopic controls through a mobile device or tablet. Programmed through JavaScript environment Three.JS, the application can be run on almost all modern devices through a simple web browser. With Red-Cyan 3D glasses, users can observe digital recreations of models in anaglyph-based 3D on a tablet recreating a phantogram. Any loaded model will look as if it's stationed on a table for an observer's viewing, contributing to the realism aspect.

Simulation of the 3D object view provided by our "PhantoView" application.

Publications

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M.M. Amiri, K. Binaee, and **J.A. Ferwerda**, "A Comparison of Colorimetric Performance of Oculus and HTC Virtual Reality Headsets," *The Frameless Journal*, Vol 1., Issue 1., Article 18, 2019, https://10.14448/Frameless.01.005.

Aaron Gerace

Digital Imaging and Remote Sensing (DIRS) Lab

Research

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

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

The Rochester Institute of Technology (RIT) has a long history of supporting calibration efforts for Landsat's thermal space-borne sensors. Recently, the United States Geological Survey (USGS) 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.

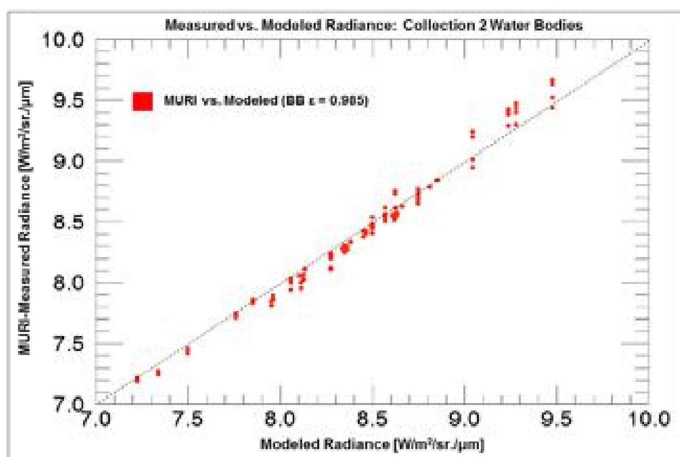
Leveraging lessons-learned from previous efforts, an eight-band thermal radiometer has been developed to measure temperature and emissivity in the longwave region of the electromagnetic spectrum. Preliminary field campaigns have begun to identify potential issues with the sensor and modifications will 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).

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

Research Team: Eon Rehman, Nina Raqueno, Tania Kleynhans

Leonardo DRS developed and flight-tested a six-band thermal sensor to demonstrate its potential utility as a low-cost space-bourne 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.

Two campaigns were conducted in 2019 to demonstrate the fidelity of the MURI six-band thermal instrument developed by Leonardo DRS. 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



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 sensor.

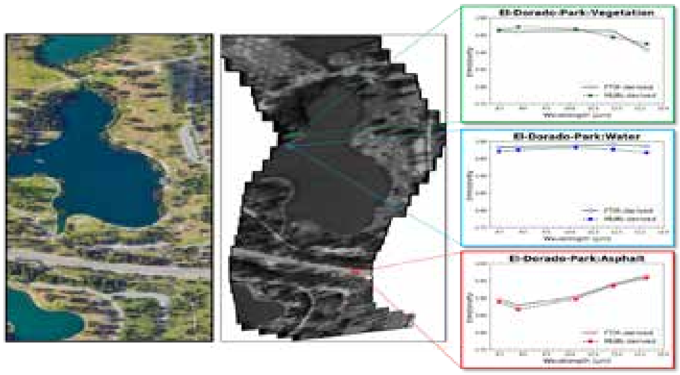


Image data collected with the six-band MURI instrument over El-Derado Park in Los Angeles, California. A five-band temperature/emissivity separation was performed with the image data for four materials. The resulting emissivities are in good agreement with library data.

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. Leonardo DRS 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.

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

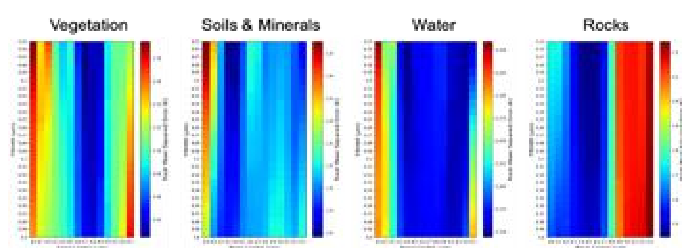
Research Team: Rehman Eon, Tania Kleynhans, Matthew Montanaro

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, the Rochester Institute of Technology (RIT) is performing simulated trade studies that investigate the impact of potential system requirements on various science applications.

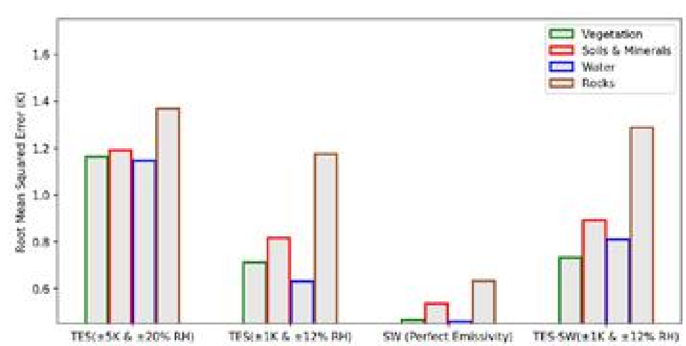
This project aims to support the definition of requirements

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

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.



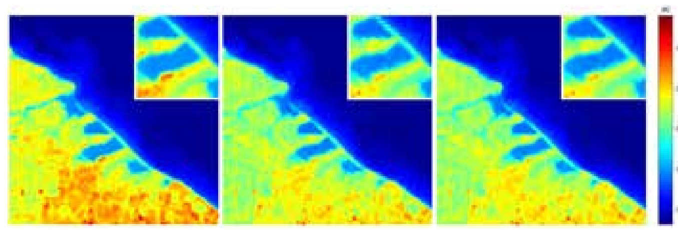
The root-mean squared error (RMSE) in the retrieved temperature from the split window algorithm by shifting of the nominal Landsat TIRS bands.

Satellite-derived land surface temperature (LST) split window algorithm development and validation

Research Team: Tania Kleynhans

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 Unit ed States Geological Survey (USGS) to support their goals of releasing a validated land-surface temperature product to users.

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 were made to the SW algorithm to compensate for aliasing appearing when difference terms are calculated. These changes are 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_201904 22_01_T1).

Publications

J. Miller, **A. Gerace**, R. Eon, M. Montanaro, R. Kremens, and J. Wehle, "Low-Cost Radiometer for Landsat Land Surface Temperature Validation," *Remote Sensing*, vol. 12, no. 3, p. 416, January 28, 2020, doi: 10.3390/rs12030416

A. Gerace, T. Kleynhans, R. Eon, and M. Montanaro, "Towards an Operational, Split Window-Derived Surface Temperature Product for the Thermal Infrared Sensors Onboard Landsat 8 and 9," *Remote Sensing*, vol. 12, no. 2, p. 224, January 9, 2020, doi: 10.3390/rs12020224

Grants

Aaron Gerace, "Improved Strategies to Enhance Calibration and Validation of Landsat Thermal Data and Their Associated Higher-Level Products," USGS, $251,402.00

Aaron Gerace, "Simulation and Modeling to Support Definition of Sustainable Land Imaging (SLI) System Requirements," NASA, $231,870.00

Aaron Gerace, "Development of strategies and instrumentation to support Landsat calibration and higher-level product verification," NASA

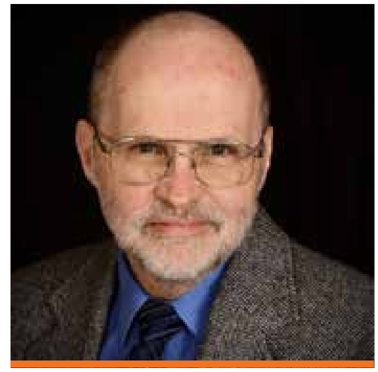
Aaron Gerace, John Kerekes, "Support to MLIS Instrument Development and Demonstration," NASA/DRS Technologies, $197,853.73

Aaron Gerace, "Support to USGS to Enhance Calibration for Current and Future Landsat Thermal Instruments," USGS, $108,141.00

Aaron Gerace, "Calibration And Assessment Of The Landsat Sensors," USGS

Richard Hailstone

NanoImaging Research Lab



Research

Professor Hailstone's research is in the area of electron microscopy. He supervises the NanoImaging Laboratory (https://www.rit.edu/cis/nanoimaging/) which houses four electron microscopes – two scanning electron microscopes (SEM) and two transmission electron microscopes. The Lab provides nanoscale and microscale imaging of materials for various research groups on campus, as well as providing an imaging center for local industry. In addition, the Lab forms collaborative partnerships with some research groups on campus.

One ongoing research project focuses on determining the point spread function (PSF) of the SEM. This metric provides information on how the imaging system blurs the object being imaged. Once this information is available, PSF deconvolution can be performed to improve the image resolution. Software and hardware for accomplishing this task has been provided by the Nanojehm Co in Albany, NY. The PSF is obtained by first imaging gold nanoparticles whose size is accurately known and whose unblurred image can be simulated. By comparing the experimental and simulated image we know the extent of blurring induced by the SEM and this allows a calculation of the PSF and then a PSF deconvolution (see Fig. 1).

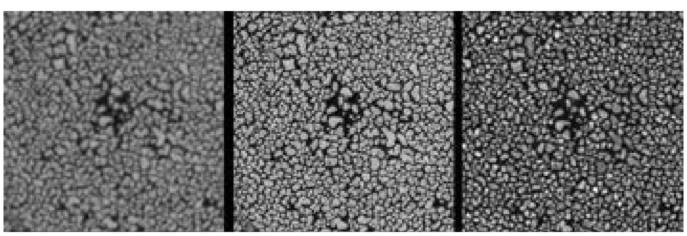


Fig. 1. A demonstration of the advantage of PSF deconvolution.

PhD student Surya Kamal is currently working on modeling the PSF of the SEM using electron wave optics. Our research is in the initial step oriented towards the end goal of obtaining better images by modeling the SEM column which contains the magnetic lens system needed for probe formation. This probe, which scans the sample to produce the image, is one of the pivotal parameters which determine the fundamental resolution of a SEM. Currently, we are developing a simulation program called SEM-Probe which uses Fourier optics of the electron beam and the lens system to predict how the probe should look under different operating conditions of the microscope (see Fig. 2). We will also offer the capability

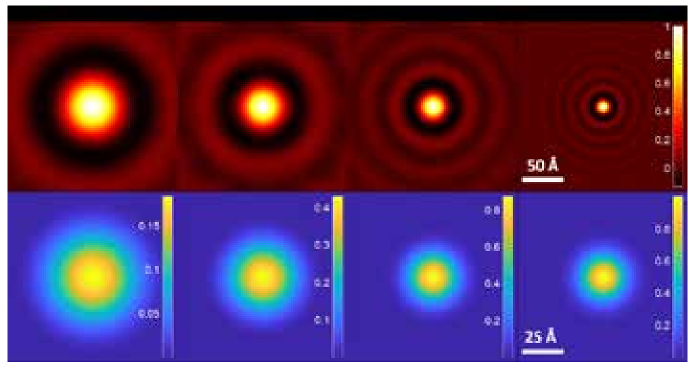


Fig. 2. Upper row – Point spread function of lens variation with accelerating voltage; Lower row- Final probe intensity distribution variation with voltage

of introducing error (aberrations) in the lens, as well as noise, and study their effect on the final probe (see Fig. 3). This kind of analytical tool would be very insightful for microscopists to deeply understand the behavior of their microscopes and potentially design computational methods to overcome these limitations to achieve better images. In the future, we will use the simulations to suggest theoretical designs for masks to produce aberration-free probes which would, in principle, inherently produce better quality images.

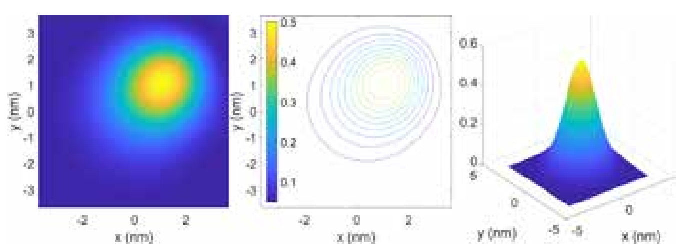


Fig. 3. Typical final probe with coma and astigmatism aberrations. Top down view (left), contour plot (center), 3-D surface plot (right)

A new project started during the 2019-2020 year is 3D SEM. As the name implies we want to provide a 3D image at the nanoscale of the material being studied. This is done by embedding the material in an epoxy resin and then creating thin (50 to 100 nm) slices with an ultramicrotome. The slices are produced as a ribbon so that the order of the slice can be determined. These slices are then imaged sequentially in the SEM. The images are then stacked to create a 3D image of the material.

While this type of 3D imaging is being done by other research groups throughout the world, one particular advantage we have is the PSF deconvolution technique described above. In the process of acquiring the image of the thin slices we can also acquire data for calculating the PSF. Then, before stacking the images, we can improve the resolution of each one and thus achieve an improved 3D image over what other groups can produce.

The ability to improve the resolution is important particularly when imaging biomaterials, which is one of the main applications of this type of imaging. To avoid damaging the biomaterial with the electron beam of the SEM, low accelerating voltages are used to produce low-energy electrons. Using low-energy electrons has the unfortunate side effect of producing a broader PSF which leads to blurrier images. We can mitigate this effect with our PSF deconvolution technique.

Besides using the 3D SEM technique to study biomaterials, the technique can also be used to study other materials such as polymers, organic structures, and various devices. We have already spent $100k to purchase a new ultramicrotome to support this project and will be spending another $63k in the coming year to upgrade the SEM with hardware and software so that automated collection of the images can be done. This upgrade is important if we want to create 3D images of significant thickness as thousands of images could be required. There is an opportunity to fund one PhD student for this project and we are currently actively trying to recruit one.

Publications

M. Massoud, J. Francis, S. Demyttenaere, N. Alharbi, C. Ge, **R.K. Hailstone**, H.N. Cheng, "Preparation and Evaluation of Composites Comprising Polypropylene and Cotton Gin Trash," presented at, *258th ACS National Meeting & Exposition*, pp. AGFD-0163 San Diego, CA, August 01, 2019.

M. Nevins, K. Quoi, **R.K. Hailstone**, E. Lifshin, "Exploring the Parameter Space of Point Spread Function Determination for the Scanning Electron Microscope – Part I: Effect on the Point Spread Function," *Microscopy and Microanalysis*, vol. 25, pp. 1167-1182, Aug. 27, 2019, https://doi.org/10.1017/S1431927619014806

M. Nevins, **R.K. Hailstone**, E. Lifshin, "Exploring the Parameter Space of Point Spread Function Determination for the Scanning Electron Microscope – Part II: Effect on Image Restoration Quality," *Microscopy and Microanalysis*, vol. 25, pp. 1185-1194, Aug. 30, 2019, https://doi.org/10.1017/S1431927619014806.

C. Ge; H.N. Cheng; M.J. Miri; **R.K. Hailstone**; J.B. Francis; Shao M. Demyttenaere; Najat A. Alharbi, "Preparation and Evaluation of Composites Comprising Polyproplyene and Cotton Gin trash," *Journal of Applied Polymer Science*, vol. 137, no. 38, March 2, 2020, https://doi.org/10.1002/app.49151

S. Bhattacharya, **R.K. Hailstone**, C. Lewis, "Thermoplastic Elastomer Blend Exhibiting Combined Shape Memory and Self Healing Functionality." *ANTEC 2020*, Virtual Conference, April 8, 2020.

D.J. McIntyre, A.P. Leggiero, **R.K. Hailstone**, I. Puchades, C.D. Cress, and B.J. Landi, "Integrated Titanium-Carbon Nanotube Conductors via Joule-heating Driven Chemical Vapor Deposition" presented at the *237th Electrochemical Society, Virtual Conference*, May 10-14, 2020, Montréal, Canada, B03-0678.

Grants

Richard Hailstone, "Nanoparticle Synthesis for Combustion Catalyst," Cerion Energy, Inc., $21,187.00

Joseph Hornak

Magnetic Resonance Lab

Research

The RIT Magnetic Resonance Laboratory (MRL) is a research and development laboratory devoted to solving real world problems with magnetic resonance.

The current problem we are addressing is changing the destructive nature of the analytical tool known as electron paramagnetic resonance (EPR) spectroscopy so it can be more useful to art conservators, art historians, conservation scientists, and archaeologists studying paintings, ceramics, and marble sculptures with cultural heritage significance. Our instrument is a low frequency EPR (LFEPR) spectrometer. It overcomes the destructive nature of conventional EPR by allowing any size sample to be studied using its unique sample probe referred to as an EPR mobile universal surface explorer (MOUSE). This hand held device can be positioned on any object and will record the EPR spectrum of a 3 mm diameter circular cap shaped region on the object.

EPR of a Four-Pigment Painting

A 10×10 cm painting of a palm tree in sand consisting of four pigments; terracotta red (TR), Han blue (HB), blue vitriol (BV), and rhodochrosite (RC); was chosen for the study. (See Figure 1.) The EPR spectra of the four pigments as a function of magnetic field (Bo) were distinct but contained overlapping features. (See Figure 2.) Four Bo locations in the spectra of the pigments, identified by the vertical lines in the Figure 2, were chosen to record spatial information by rastering the sensitive region of the MOUSE across the painting. Since the EPR spectrum at any location in the painting is the weighted sum of the four spectral components at that point, the amount of each pigment can be determined from four Bo locations. The spatial distribution of these four pigments were used to control the amount of blue, green, red, and yellow in a resultant image depicted in Figure 3. Other approaches are being considered to improve upon the imaging.

Fig 1. Optical image of the 10x10cm painting.

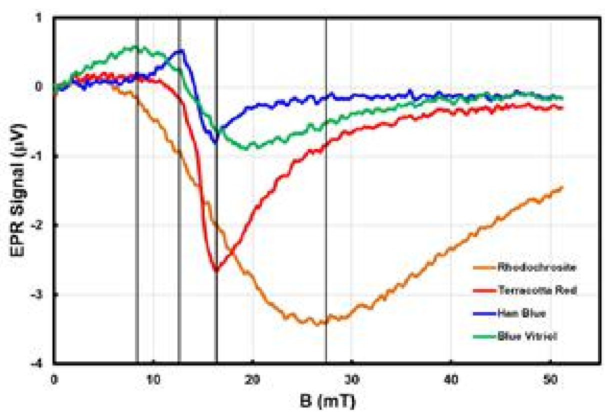


Fig. 2. LFPEPR spectra fo r the four pigments in the palm tree painting. Vertical lines represent the locations of the Bo values used in the analysis

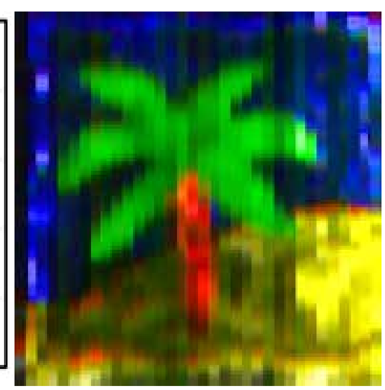


Fig. 3. Colorized EPR spectra of the painting based on the RC signal as red, BV as green, HB as blue and RC as yellow.

Publications

H.F. Schmitthenner, D.E. Dobson, K.G. Jones, N. Akporji, D.Q.M. Soika, K.L. Nastiuk, **J.P. Hornak**, "Modular Synthesis of DOTA-Metal-Based PSMA-Targeted Imaging Agents for MRI and PET of Prostate Cancer," *Chem. Eur. J.*, 25: 13848–13854 (2019).

E.A. Bogart, H. Wiskoski, M. Chanthavongsay, A. Gupta, **J.P. Hornak**, "The Noninvasive Analysis of Paint Mixtures on Canvas Using an EPR MOUSE," *Heritage*, 3:140-151 (2020).

J.P. Hornak, "The development of low frequency EPR spectroscopy for studying objects with cultural heritage significance." in *Spectroscopic Techniques for Archaeological and Cultural Heritage Research,* Edited by A.K. Shukla, IOP Publishing (2020).

H. Wiskoski, E.A. Bogart, M. Chanthavongsay, A. Gupta, **J.P. Hornak**, "Using an EPR Mobile Universal Surface Explorer to Non-Destructively Analyze Mixtures of Paint on Canvas," *Rochester Academy of Science 40th Annual Fall Scientific Paper Session*, Rochester, NY, November 2019

E.A. Bogart, M. Chanthavongsay, A. Gupta, H. Wiskoski, **J.P. Hornak**, "Identification of Paint Pigment Mixtures using the EPR Mobile Universal Surface Explorer," *Eastern Analytical Symposium*, Somerset, NJ, November 2019.

Emmett Ientilucci

Digital Imaging and Remote Sensing (DIRS) Lab

Research

The nature of our group is to perform research in the area of Remote Sensing. This includes general algorithm development and the development of image processing techniques as applied to remote sensing imagery, specifically. Additionally, we are ramping up our efforts in the area of instrument calibration (i.e., radiometric, spectral as well as spatial). This is due to our 20 inch integrating sphere (i.e., radiometric cal), OL 750 monochromator and pencil line sources (spectral cal) and on-going modifications to our EO Industries collimator (6-inch mirror for spatial cal.). In the next year we will be developing an FEL NIST-traceable lamp / Lambertian plaque radiance standard to accommodate a wide field of view imaging systems, for example. Below we highlight some of the activities over the past year.

UAS / Remote Sensing Conference

On February 25-27, 2019, Dr. Emmett Ientilucci chaired the 3rd workshop on Systems and Technologies for Remote Sensing Applications Through Unmanned Aerial Systems, or simply STRATUS 2019, which was held at RIT and sponsored by the IEEE Geoscience and Remote Sensing Society (GRSS). The focus of this event was to have papers and presentations in the area of Remote Sensing / UAS. Specifically, we covered topics such as the latest regulations from the FAA, UAS- hardware, algorithms, environmental monitoring, precision agricultural, and applications related to water bodies.

We had 110 participants from 7 countries and 10 states in the US, as seen in Figure 1. The committee consisted of representatives from RIT, Cornell, SUNY ESF, UB, and Hobart and William Smith Colleges. Tutorials were given by representatives from Labsphere, Pix4D and Beamio. Sponsors and vendors included Hyspex, Headwall Photonics, Beamio, Harris Corporation, Gapwireless, EagleHawk and GRSS. Prizes ($200 each) were given for best student paper, presentation, and poster. Our keynotes were Dr. Sally Rockey, Executive Director of the Foundation for Food and Agriculture Research (FFAR) and Dr. Steven Thomson, National Program Leader for USDA, National Institute of Food and Agriculture (NIFA). The event was marketed in the Rochester Business Journal, RIT University News, RIT Message Center, and an interview with WROC TV Channel 8 (https://www.rochesterfirst.com/news/local-news/stratus-conference-hosted-at-rit/1810686228). Our next event will be May 17-19, 2021 at the University at Buffalo (www.Stratus-Conference.com).

(Top) 3rd IEEE GRSS UAS Workshop in Rochester, NY, which attracted 110 guests. (Bottom) Dr. Emmett Ientilucci with keynote speaker, Dr. Sally Rockey, Executive Director of the Washington, DC-based Foundation for Food and Agriculture Research.

Research Highlights

Funding, between mid-2019 through mid-2020, came from a variety of sources including hyperspectral system consulting work with HyperSAT Systems, LLC., image science research with Oak Ridge National Labs, satellite calibration research with Labsphere, Inc., explosives and plume analysis with Austin Powder, remote sensing system modeling and simulation work with Spectral Sciences, Inc. and surveillance augmentation techniques for commercial satellite imaging systems with Kitware, Inc.

Over a dozen presentations were given at various conferences, workshops, and sponsor meetings including three invited talks:

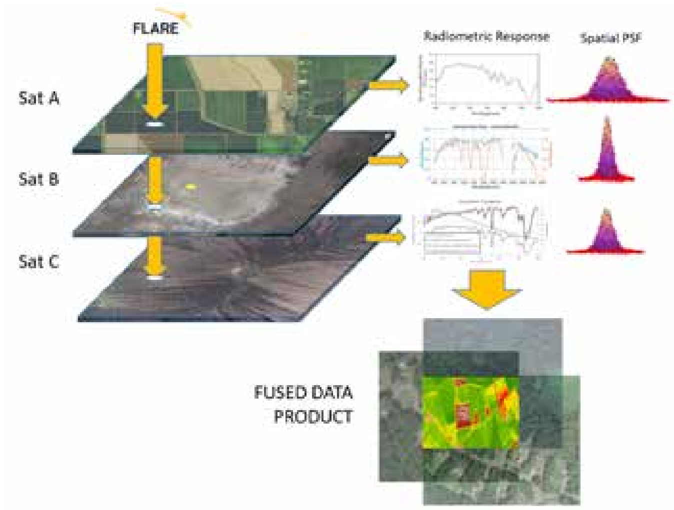
- **Invited**. IEEE Rochester Engineering Symposium, "Remote Sensing and Object Detection using Aerial Spectral Imaging Data", Rochester Convention Center, Rochester, NY.
- **Invited**. Talk to the University of Lethbridge, Alberta, Canada, "RIT's Center for Imaging Science and Digital Image and Remote Sensing Lab".
- **Invited**. Guest speaker (Skype) at the Advanced Machine Learning Techniques for Climate Informatics, Indian Statistical Institute (ISI), Kolkata, India, "Atmospheric Compensation of Remote Sensing Data," November 2019.

Overall, research resulted in the publication papers in journals such as Geoscience and Remote Sensing (GRS) Magazine, IEEE Transactions on Geoscience and Remote Sensing, and the Journal of the DSIAC Defense Systems Information Analysis Center. There was also an Invited Paper that was published in the proceedings of the OSA Education and Training in Optics and Photonics. Of note, is a paper in the June issue of *GRS Magazine*, which has an impact factor of around 13, entitled, "Atmospheric Compensation of Hyperspectral Data". This 19-page paper was part of a special issue of the magazine focusing on hyperspectral imaging.

Below, we touch upon selected research areas including, satellite calibration techniques, detection and mitigation of shadows in satellite imagery, and recent efforts in modeling and simulation to support hyperspectral target detection algorithm development.

Satellite Calibration Research

We have been working with Labsphere Inc., on a new capability for performing vicarious radiometric calibration of high, medium, and low spatial resolution sensors. The system is called FLARE, see Figure 2 below. The SPecular Array Radiometric Calibration (SPARC) method employs convex mirrors to create calibration targets for deriving



The FLARE Network will be distributed around the world for satellites to access high quality radiometric and spatial calibration. Low uncertainty and spectral stability will unlock the capability for satellites to perform data fusion across various resolutions and spectral bands.

absolute calibration coefficients of Earth remote sensing systems in the solar reflective spectrum and ideal impulse responses for image quality studies. Radiometric calibration is accomplished by varying the number of mirrors (i.e., at-sensor radiance) observed by the satellite in order to create absolute gain coefficients (DN to radiance) based on an empirical line method. RIT is designing the algorithms to perform image quality analysis on the ideal point sources created by the convex mirrors. In recent advancements, ideal line targets are being studied for comparison to edge target methods. Moreover, image quality techniques such as the Rayleigh Resolution Criteria are being investigated by using pair-point mirror configurations at various separation distances. The combination of these arrays with a targeting station is the basis for a new, on-demand commercial calibration network which has been named FLARE. We are currently designing algorithms, as well as processing data, for the generation of PSF's and MTF's on imagery from the FLARE network.

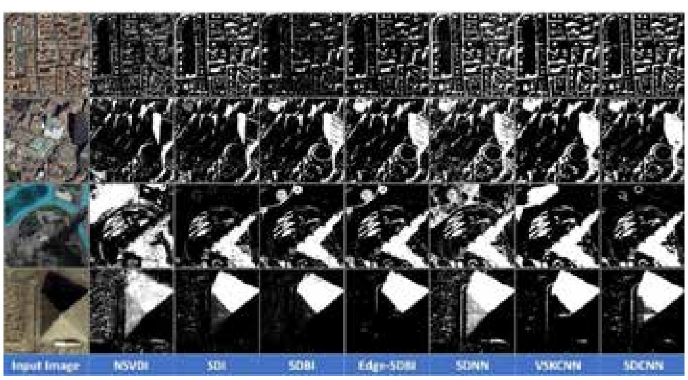
Shadow Detection and Mitigation in Satellite Imagery

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. We have 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

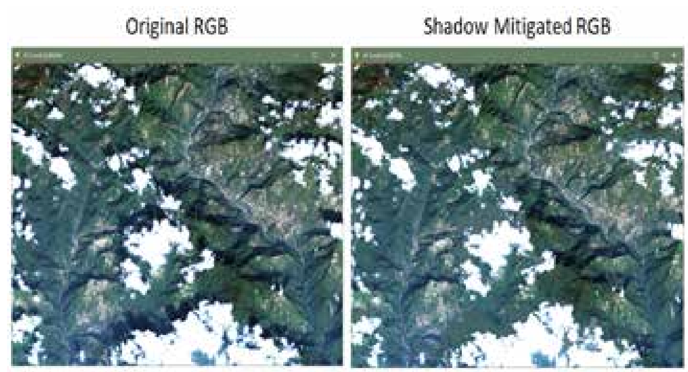
Sized Kernels Convolutional Neural Network (VSKCNN) and the Shadow Detect Convolutional Neural Network (SDCNN)). Results can be seen in Figure 3. In addition, we seek to mitigate shadows using physics-based and machine learning approaches. Figure 4 shows results of our physics-based approach where we assume, as input, a multispectral image and co-registered cloud shadow map which are then used to calculate shadowed pixel spectral statistics and adjusting to match the statistics of spectrally similar sunlit pixels resulting in a shadow mitigated multispectral .

Hyperspectral Simulation and Modeling to Support Target Detection

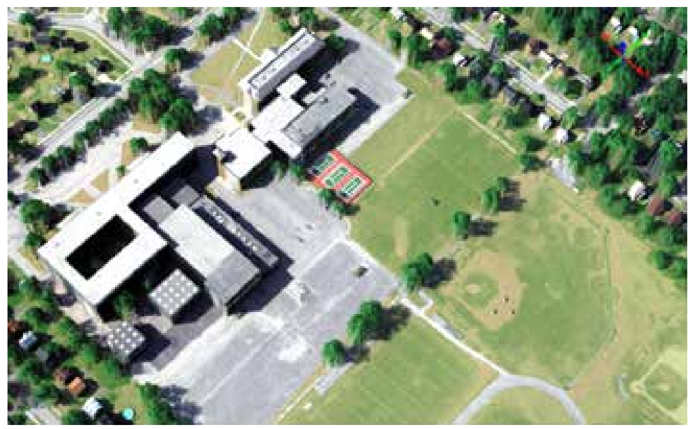
There is a need to advance hyperspectral exploitation algorithms by incorporating 3D spatial information for improved target detection and identification. Hyperspectral imaging (HSI) has demonstrated utility for material classification and target detection. Using HSI alone can produce false alarms and 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 our recent efforts is to improve and expand upon previous work with emphasis on target detection, rather than material classification. DIRSIG has been used to generate both HSI and LiDAR scenes containing target shapes with spectra of interest to be placed throughout our Megascene 1 image (see Figure 5). The objects have been placed in locations ranging from wide-open to hidden within building and tree line shadows. Additionally, confuser targets were also placed around the scene with similar spectra and 3D shape in order to test the robustness of detection algorithms.



Shadow mask output for all the algorithms on a Worldview 2 data (Pulakurthi et. al.).



Thumbnail RGB images of a Worldview 2 image product before (left) and after (right) shadow mitigation is applied (Gartely, M. et. al.).



Hyperspectral (i.e., 500 to 2500 nm) DIRSIG rendering (w/o sensor PSF) of Megascene 1 with RGB bands overlayed onto a DIRSIG generated 3D LiDAR image. Notice T-72 tank targets placed in the open, along a tree-line, and next to a building (Gartley et. al.).

Publications

A. Savakis, N. Nagananda, J. Kerekes, **E. Ientilucci**, R. Blue, W. Hicks, T. Rovito and E. Blasch, "Change Detection in Satellite Imagery with Region Proposal Networks," *Journal of the DSIAC Defense Systems Information Analysis Center,* Vol. 6, No. 4, (Nov. 2, 2019).

E.J. Ientilucci, "Lab-based Radiometric Concepts for Undergraduate and Graduate Students," (Invited Paper), *Proceedings Volume 11143: Fifteenth Conference on Education and Training in Optics and Photonics: ETOP 2019*, July 2, 2019, Quebec City, Quebec, CA https://doi.org/10.1117/12.2523868.

E. Ientilucci, "GRSS Western New York Chapter Status and Activities," *IEEE Geoscience and Remote Sensing Magazine,* volume 7, issue 3, pages 133-136, (Sept. 2019). DOI: 10.1109/MGRS.2019.2928931

E. Ientilucci, chair/editor, *Proceedings Volume 11130, Imaging Spectrometry XXIII (2019), SPIE Optical Engineering + Applications*, Sept. 12, 2019, San Diego, CA, https://doi.org/10.1117/12.2551564

A. Rangnekar, N. Mokashi, **E. Ientilucci**, C. Kanan, and M. Hoffman, "AeroRIT: A New Scene for Hyperspectral ImageAnalysis," *Transactions on Geoscience and Remote Sensing (TGARS)*, Vol. 58, No. 11, Pages 8116-8124, (April 27, 2020), DOI: 10.1109/ TGRS.2020.2987199.2019

Grants

E. Ientilucci, HSI Sensor System Engineering Support, HyperSat Systems LLC, $128,338, 10/18/2019 – 10/18/2021

E. Ientilucci, Fundamental Image Science Research, ORNL, $359,089, 3/14/2019 – 2/28/2021

E. Ientilucci, Support to FLARE Project, Labsphere, Inc., $74,051, 11/1/2019 – 10/31/2020

E. Ientilucci, Quantitative Analysis of Nitrous Oxide after Blast Fumes by Drone Monitoring, Austin Powder Co., $127,690, 9/1/2019 – 12/23/2020

E. Ientilucci, Simulation and Modeling to Support Target Detection, Spectral Sciences, Inc., $24,950, 4/1/2020 – 9/30/2020

J. Kerekes and **E. Ientilucci**, Global Surveillance Augmentation Using Commercial Satellite Image Systems, Kitware, Inc., $302,239, 2/12/2018 – 5/9/2022

A. Savakis and **E. Ientilucci**, Global Surveillance Augmentation for Deep Learning, NYS Department of Economic Development, $29,750, 7/1/2019 – 6/30/2020

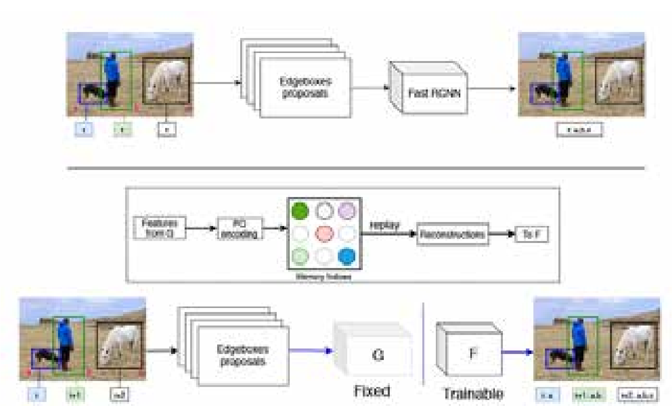
Christopher Kanan

Machine and Neuromorphic Perception Lab

Research

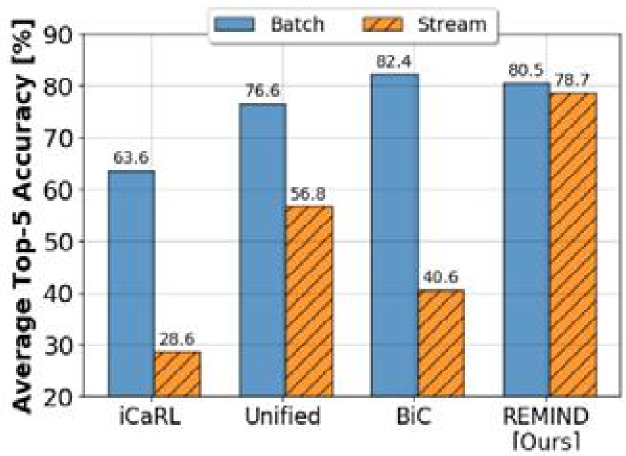
Christopher Kanan's lab works to advance the state-of-the-art in artificial intelligence (AI). Most of the lab's efforts are directed toward advancing the capabilities of deep neural networks and on using machine learning to solve problems in computer vision. The lab's recent work can be divided into two main thrusts: 1) enabling lifelong learning in deep neural networks, and 2) visually grounded language understanding.

While deep neural networks are now capable of rivaling or exceeding human capabilities for some tasks, conventional methods cannot learn new information over time without suffering from catastrophic forgetting. In other words, a conventional network that learns to recognize ten people and then is later updated to recognize five new people will usually forget the initial ten. The naive fix is to mix the new data with the old data and re-train the model from scratch, but this is computationally wasteful. Enabling networks to learn over time is needed for many applications, including fast learning for embedded devices, robotics, and user customization. Dr. Kanan and his students have been working on this problem for several years. This year, the lab won a grant from NSF to enable Dr. Kanan's group to keep pushing the field forward. The lab has published numerous papers in this space, including new 2020 papers in ECCV, BMVC, and the CVPR Workshop on Continual Learning in Computer Vision.



In RODEO, which was published in BMVC-2020, Dr. Kanan's lab created the first system for online object detection.

Another major research thrust in the lab is developing systems capable of visually grounded language understanding. These systems process images and videos



In RODEO, which was published in BMVC-2020, Dr. Kanan's lab created the first system for online object detection.

guided by language. Dr Kanan's lab is especially well known for their work on visual question answering (VQA), one of the best studied visually grounded language understanding problems. In VQA, an algorithm is given a text-based question and an image, and it must produce a text-based answer to the query. This is a challenging problem that combines many aspects of computer vision: object segmentation, object detection, object recognition, activity detection, object counting, and more. Answering questions about images often requires reasoning and common sense, making this problem an important next step in creating flexible multi-task computer vision algorithms. With CIS PhD students Kushal Kafle and Robik Shrestha, Dr. Kanan published papers in Frontiers in AI, ACL, and NeurIPS on VQA.

PhD Students

Kushal Kafle – Graduated – Now Research Scientist at Adobe Research
Ryne Roady – Graduated – US Air Force Student
Tyler Hayes
Robik Shretha
Manoj Acharya
Gianmarco Callalli

Publications

D. Teney, K. Kafle, R. Shrestha, E. Abbasnejad, **C. Kanan**, A. van den Hengel, “On the Value of Out-of-Distribution Testing: An Example of Goodhart’s Law,” in *Proc. Advances in Neural Information Processing Systems 33 (NeurIPS)*, Vancouver, CA, Dec. 8-14, 2019.

R. Kothari, Z. Yang, **C. Kanan**, R. Bailey, J.B. Pelz, G.J. Diaz. “Gaze-in-wild: A dataset for studying eye and head coordination in everyday activities,” *Sci Rep*, 10, 2539 (Feb. 13, 2020), https://doi.org/10.1038/s41598-020-59251-5

K. Kafle, R. Shrestha, S. Cohen, B. Price, **C. Kanan**, “Answering Questions about Data Visualizations using Efficient Bimodal Fusion,” in *IEEE Winter Applications of Computer Vision Conference (WACV)*, March 1-5, 2020, https://dblp.org/rec/conf/wacv/KafleSPCK20.

R. Roady, T. L. Hayes, H. Vaidya, **C. Kanan**, “Stream-51: Streaming Classification and Novelty Detection From Videos,” *Proc. IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR) Workshop on Continual Learning in Computer Vision (CLVISION)*, June 14, 2020, pp. 228-229.

T.L. Hayes, **C. Kanan**, “Lifelong Machine Learning with Deep Streaming Linear Discriminant Analysis,” *CVPR Workshop on Continual Learning in Computer Vision (CLVISION)*, June 14, 2020, https://arxiv.org/abs/1909.01520v3.

K. Kafle, R. Shrestha, **C. Kanan**,”Challenges and Prospects in Vision and Language Research,” *Front. Artif. Intell.*, Dec. 13, 2019, https://doi.org/10.3389/frai.2019.00028

N. Seedat, **C. Kanan**, “Towards calibrated and scalable uncertainty representations for neural networks,” in *33rd Conference on Neural Information Processing Systems (NeurIPS 2019): 4th workshop on Bayesian Deep Learning*, Vancouver, Canada, Dec. 13, 2019.

A.K. Chaudhary, R. Kothari, M. Acharya, S. Dangi, N. Nair, R. Bailey, **C. Kanan**, G. Diaz, J.B. Pelz, “RITnet: Real-time Semantic Segmentation of the Eye for Gaze Tracking,” *The 2019 OpenEDS Workshop at ICCV-2019: Eye Tracking for VR and AR*. [Winner of the Facebook eye semantic segmentation challenge]

Grants

Kanan, Christopher, Fast and Efficient Continual Learning without Catastrophic Forgetting, Army, $41,482.00

Kanan, Christopher, RI: Small: Lifelong Multimodal Concept Learning. NSF Award #1909696. $499,960.

Joel Kastner

Laboratory for Multiwavelength Astrophysics

Research

In Fall 2019 and Spring 2020, a team led by CIS faculty member Joel Kastner used NASA's flagship Great Observatory, the Hubble Space Telescope, to obtain images of two planetary nebulae. Planetary nebulae are stars, somewhat more massive than the Sun, that have been caught in the act of dying, redistributing the products of stellar core fusion back into interstellar space in the process.

The initial results from these Hubble observations were the subject of a press release by the Space Telescope Science Institute, which operates Hubble and manages its science program on behalf of NASA. In the words of the STScI press release (https://hubblesite.org/contents/news-releases/2020/news-2020-31):

"Planetary nebulae, whose stars shed their layers over thousands of years, can turn into crazy whirligigs while puffing off shells and jets of hot gas. New images from the Hubble Space Telescope have helped researchers identify rapid changes in material blasting off stars at the centers of two nebulae — causing them to reconsider what is happening at their cores.

"In the case of NGC 6302, dubbed the Butterfly Nebula, two S-shaped streams indicate its most recent ejections and may be the result of two stars interacting at the nebula's core. In NGC 7027, a new cloverleaf pattern — with bullets of material shooting out in specific directions — may also point to the interactions of two central stars. Both nebulas are splitting themselves apart on extremely short timescales, allowing researchers to measure changes in their structures over only a few decades. This is the first time both nebulas have been studied from near-ultraviolet to near-infrared light, a complex, multi-wavelength view only possible with Hubble.

"As nuclear fusion engines, most stars live placid lives for hundreds of millions to billions of years. But near the end of their lives they can turn into crazy whirligigs, puffing off shells and jets of hot gas. Astronomers have employed Hubble's full range of imaging capabilities to dissect such crazy fireworks happening in two nearby young planetary nebulas. NGC 6302 is dubbed the Butterfly Nebula because of its wing-like appearance. In addition, NGC 7027 resembles a jewel bug, an insect with a brilliantly colorful metallic shell.

"The researchers have found unprecedented levels of complexity and rapid changes in jets and gas bubbles blasting off of the stars at the centers of both nebulas. Hubble is allowing the researchers to converge on an understanding of the mechanisms underlying the chaos.

"`When I looked in the Hubble archive and realized no one had observed these nebulas with Hubble's Wide Field Camera 3 across its full wavelength range, I was floored,' said Joel Kastner of Rochester Institute of Technology, Rochester, New York, leader of the new study. `These new multi-wavelength Hubble observations provide the most comprehensive view to date of both of these spectacular nebulas. As I was downloading the resulting images, I felt like a kid in a candy store.'

"By examining this pair of nebulas with Hubble's full, panchromatic capabilities — making observations in near-ultraviolet to near-infrared light — the team has had several `aha' moments. In particular, the new Hubble images reveal in vivid detail how both nebulas are splitting themselves apart on extremely short timescales — allowing astronomers to see changes over the past couple decades. Some of this rapid change may be indirect evidence of one star merging with its companion star.

"'The nebula NGC 7027 shows emission at an incredibly large number of different wavelengths, each of which highlights not only a specific chemical element in the nebula, but also the significant, ongoing changes in its structure,' said Kastner. The research team also observed the Butterfly Nebula, which is a counterpart to the `jewel bug' nebula: Both are among the dustiest planetary nebulas known and both also contain unusually large masses of gas because they are so newly formed. This makes them a very interesting pair to study in parallel, say researchers.

"Hubble's broad multi-wavelength views of each nebula are helping the researchers to trace their histories of shock waves. Such shocks typically are generated when fresh, fast stellar winds slam into and sweep up more slowly expanding gas and dust ejected by the star in its recent past, generating bubble-like cavities with well-defined walls.

"Researchers suspect that at the hearts of both nebulas are

— or were — two stars circling around each other, like a pair of figure skaters. Evidence for such a central "dynamic duo" comes from the bizarre shapes of these nebulas. Each has a pinched, dusty waist and polar lobes or outflows, as well as other, more complex symmetrical patterns.

"A leading theory for the generation of such structures in planetary nebulas is that the mass-losing star is one of two stars in a binary system. The two stars orbit one another closely enough that they eventually interact, producing a gas disk around one or both stars. The disk is the source of outflowing material directed in opposite directions from the central star.

"Similarly, a smaller star of the pair may merge with its bloated, more rapidly evolving stellar companion. This also can create outflowing jets of material that may wobble over time. This creates a symmetric pattern, perhaps like the one that gives NGC 6302 its `butterfly' nickname. Such outflows are commonly seen in planetary nebulae.

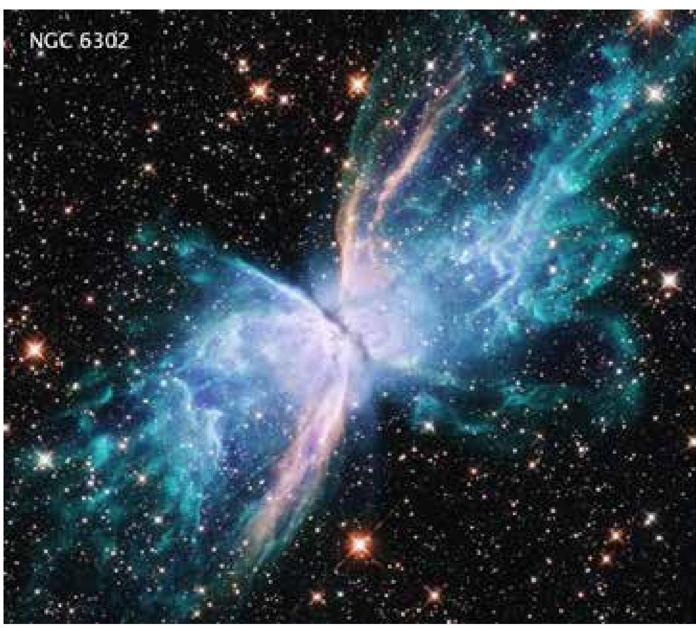
"Imagine a lawn sprinkler spinning wildly, tossing out two S-shaped streams. At first it appears chaotic, but if you stare for a while, you can trace its patterns. The same S-shape is present in the Butterfly Nebula, except in this case it is not water in the air, but gas blown out at high speed by a star. And the `S' only appears when captured by the Hubble camera filter that records near-infrared emission from singly ionized iron atoms.

" 'The S-shape in the iron emission from the Butterfly Nebula is a real eye-opener,' Kastner said. The S-shape directly traces the most recent ejections from the central region, since the collisions within the nebula are particularly violent in these specific regions of NGC 6302.

"The research team's new images of NGC 7027 show emission from singly ionized iron that closely resembles observations made by NASA's Chandra X-ray Observatory in 2000 and 2014 as part of earlier research by Kastner, team member [and 2010 RIT AST PhD recipient] Rodolfo Montez Jr. of the Center for Astrophysics | Harvard & Smithsonian.

"The research team also includes [AST] Ph.D. students Jesse Bublitz and Paula Moraga of Rochester Institute of Technology, Bruce Balick of the University of Washington, and Adam Frank and Eric Blackman of the University of Rochester."

These initial results appeared in the paper "First Results from a Panchromatic HST/WFC3 Imaging Study of the Young, Rapidly Evolving Planetary Nebulae NGC 7027 and NGC 6302" (J. Kastner et al.), which was published on June 15, 2020 in the journal Galaxies.



Publications

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Kastner, J. H., Bublitz, J., Balick, B., Montez, R., Frank, A., and Blackman, E., "First Results from a Panchromatic HST/WFC3 Imaging Study of the Young, Rapidly Evolving Planetary Nebulae NGC 7027 and NGC 6302", *Galaxies*, vol. 8, no. 2. p. 49, June 15, 2020. doi: 10.3390/galaxies8020049.

Sargent, B., Riley, A., Srinivasan, S., & **Kastner, J.** (2020). "Evolved Star Mass Loss in the Galactic Bulge from Multi-Wavelength Surveys." *Bulletin of the AAS*, 52(3). Retrieved from https://baas.aas.org/pub/aas236-306p01-sargent

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Bublitz, J., et al, "Irradiation Investigation: Exploring the Molecular Gas in NGC 7293", *Galaxies*, vol. 8, no. 2. p. 32, April 8, 2020. doi: 10.3390/galaxies8020032.

Binks, A. S., et al, "VizieR Online Data Catalog: Supplementary data for 146 candidate young stars (Binks+, 2020)", *VizieR Online Data Catalog*, 2020.

Aleman, I., Bernard-Salas, J., **Kastner, J. H.**, Ueta, T., and Villaver, E., "WORKPLANS: Workshop on Planetary Nebula Observations", *Galaxies*, vol. 8, no. 1. p. 23, March 16, 2020. doi: 10.3390/galaxies8010023.

Dickson-Vandervelde, D. A., Wilson, E. C., and **Kastner, J. H.**, "Identification of the Youngest Known Substellar Object within 100 pc", *Research Notes of the American Astronomical Society*, vol. 4, no. 2. Feb. 2020. doi: 10.3847/2515-5172/ab7344.

A. S Binks, M. Chalifour, **J. H Kastner**, D. Rodriguez, S. J Murphy, D.A. Principe, K. Punzi, G.G. Sacco, J. Hernández, "A kinematically unbiased, all-sky search for nearby, young, low-mass stars," Monthly Notices of the Royal Astronomical Society, Volume 491, Issue 1, January 2020, Pages 215–234, https://doi.org/10.1093/mnras/stz3019doi: 10.1093/mnras/stz3019.

Dickson-Vandervelde, D. A., Wilson, E. C., and **Kastner, J.**, "Reconsidering Eps Cha Membership and Properties with Gaia DR2", *Bull. of the AAS*, vol. 235, Jan. 2020.

Zuckerman, B., Klein, B., and **Kastner, J.**, "The Nearby, Young, χ^1 Fornacis Cluster: Membership, Age, and an Extraordinary Ensemble of Dusty Debris Disks", *The Astrophysical Journal*, vol. 887, no. 1. Dec. 2019. doi: 10.3847/1538-4357/ab45ea.

Hily-Blant, P., Magalhaes de Souza, V., **Kastner, J.**, and Forveille, T., "Multiple nitrogen reservoirs in a protoplanetary disk at the epoch of comet and giant planet formation", *Astronomy and Astrophysics*, vol. 632. Dec. 2019. doi: 10.1051/0004-6361/201936750.

Shen, B., Pilachowski, C. A., Punzi, K. M., **Kastner, J.** H., Melis, C., and Zuckerman, B., "The Barium Abundance in the Young Star RZ Piscium", *Research Notes of the American Astronomical Society*, vol. 3, no. 11. 2019. doi: 10.3847/2515-5172/ab5647.

Gagné, J., et al"The opportunity of young nearby associations with the advent of the Gaia mission", in *Canadian Long Range Plan for Astronomy and Astrophysics White Papers*, 2019, vol. 2020. doi: 10.5281/zenodo.3725793.

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P.J. Green, R. Montez, F. Mazzoni, J. Filippazzo, S.F. Anderson, O. De Marco, J.J. Drake, J. Farihi, A. Frank, **J.H. Kastner**, "A Chandra Study: Are Dwarf Carbon Stars Spun Up and Rejuvenated by Mass Transfer?", The Astrophysical Journal, vol. 881, no. 1. 2019. doi: 10.3847/1538-4357/ab2bf4.

Ruíz-Rodríguez, D., **Kastner, J. H.**, Dong, R., Principe, D. A., Andrews, S. M., and Wilner, D. J., "Constraints on a Putative Planet Sculpting the V4046 Sagittarii Circumbinary Disk", *The Astronomical Journal*, vol. 157, no. 6. 2019. doi: 10.3847/1538-3881/ab1c58.

Kastner, J., "The Early Evolution of Stars and Exoplanet Systems: Exploring and Exploiting Nearby, Young Stars", *Bulletin of the American Astronomical Society (Astro2020 Decadal Review)*, vol. 51, no. 3. 2019.

Rau, G., "Cool, evolved stars: results, challenges, and promises for the next decade", *Bulletin of the American Astronomical*

Society (Astro2020 Decadal Review), vol. 51, no. 3. 2019.

Wolk, S., et al, "X-ray Studies of Exoplanets", Bulletin of the American Astronomical Society (Astro2020 Decadal Review), vol. 51, no. 3. 2019.

Grants

Kastner, Joel, "Exploring Planet Formation in the Nearest Known Protoplanetary Disks," NASA-National Aeronautics and Space Administration, $260,820

Kastner, Joel, "Young and Rapidly Evolving: a Panchromatic WFC3 Imaging Study of the Planetary Nebulae NGC 7027 and NGC 6302," Space Telescope Science Institute, $91,347

Kastner, Joel, "THE NATURE OF X-RAYS FROM YOUNG STELLAR OBJECTS IN THE ORION NEBULA CLUSTER," SAO/CXC, $12,000

Andrew Robinson, **Kastner, Joel**, O'Shaughnessy, Richard, Zemcov, Michael, "RIT Space Grant 2015-18 Proposal," NASA-National Aeronautics and Space Administration / Cornell University, $77,000

John Kerekes

Greening Diplomacy Initiative

Research

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 Office of Management.

GDI works to enhance the environmental sustainability of the Department of State's global operations. One of their activities is to manage a network of regulatory grade air quality monitors at over 60 overseas U.S. embassies and consulates. Prof. Kerekes advised State on how to obtain environmental data from satellites to complement these ground measurements. He also participated in numerous interagency meetings representing the State department on topics related to satellite monitoring of the environment.

While away Prof. Kerekes continued to advise his graduate students on their research and maintained his active support to the IEEE Geoscience and Remote Sensing Society serving as their Chief Financial Officer.

Continuing Students Advised:

Jobin Mathew, PhD
Cara Murphy, PhD
Emily Myers, PhD
Cody Webber, PhD

Students advised who graduated in August 2019:

Sanghui Han, PhD - Employed at Resonant Sciences
Keegan McCoy, PhD - Employed at United States Air Force

Publications

S. Han, **J. Kerekes**, S. Higbee, L. Siegel, and A. Pertica, "Prediction and Assessment Comparison for Optimizing Spectral Imaging System Design," in *Proc. of the 2019 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pp. 445-448, Yokohama, Japan, July 2019, doi: 10.1109/JMASS.2020.2994273.

Z. Cui, **J. Kerekes**, "Potential of Red Edge Spectral Bands in Future Landsat Satellites on Agroecosystem Canopy Chlorophyll Content Retrieval," in *Proc. of the 2019 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, pp. 7168-7171, Yokohama, Japan, July 2019, doi: 10.1109/IGARSS.2019.8898783.

E. Myers, **J.P. 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*, pp. 1-21, October, 2019, https://doi.org/10.3390/rs11212558.

S. Han, **J. Kerekes**, S. Higbee and L. Seigel, "Optimizing Requirements for a Compact Spaceborne Adaptive Spectral Imaging System in Subpixel Target Detection Applications," *IEEE Journal on Miniaturization for Air and Space Systems*, vol. 1, no. 1, pp. 32-46, June 2020, doi: 10.1109/JMASS.2020.2994273.

Grants

John Kerekes, Andreas Savakis, "Global Surveillance Augmentation Using Commercial Satellite Imaging Systems (Phase III)," USAF/Kitware, Inc.

John Kerekes, Aaron Gerace, "Support to MLIS Instrument Development and Demonstration," NASA/DRS Technologies

John Kerekes, "Systems Engineering Support For Next Generation Land Remote Sensing Systems," NASA

Guoyu Lu

Intelligent Vision and Sensing Lab

Research

Dr. Guoyu Lu organized the Joint Workshop on Long-Term Visual Localization, Visual Odometry and Geometric and Learning-based SLAM, in conjunction with CVPR 2020 (Conference on Computer Vision and Pattern Recognition). The workshop provided a forum for visual odometry and localization, which can be applied to autonomous driving, augmented reality, mobile computing, etc. It attracted more than 200 participants from all around the world. The workshop included 19 world-renowned keynote speakers from both academic and industrial organizations.

The lab has won SICK Inc. TiM$10K Challenge (2020) on the topic of "Converting 2D LiDAR into 3D LiDAR", which has been reported by multiple media outlets.

The lab's master student, Devarth Parikh, has graduated with one peer-reviewed first author paper and joined Ford Motor company as a research engineer. Another Electronic Engineering master student, Pronav Dattatray Kelkar, graduated from the lab in 2019 and joined Amazon as a software engineer. Yogeshwar Vishnu Jadhav, another EE master student, also graduated from the lab in summer of 2020. Undergraduate students completing their senior projects in the lab include Ian Smith, Donald Shultz, and Christian Lusardi. Christian later continued his studies as a graduate student. One high school student, Amy Ruan, also conducted her summer internship in the lab in 2019 summer.

The lab's first PhD student, Yawen Lu, published 4 first author peer-reviewed papers in his second year.

In the coming year the lab will continue the ongoing research in the areas of single image depth estimation, thermal and visible image fusion, thermal image 3D modeling, 3D object detection and pose estimation, 3D gaze localization, and plant phenotyping. The research portfolio will also expand to include broader areas such as computer vision applications in agriculture, face reconstruction from a single image, and image modality translation.

Publications

Zhelin Yu, Lidong Zhu, **Guoyu Lu**, "An Improved Phase Correlation Method for Stop Detection of Autonomous Driving," *IEEE Access 2020*, doi: 10.1109/ACCESS.2020.2990227

Zhen Wang, Guoshan Xu, Yong Ding, Bin Wu, **Guoyu Lu**, "A vision-based active learning convolutional neural network model for concrete surface crack detection," *Advances in Structural Engineering*, June 2020, doi:10.1177/1369433220924792

Yawen Lu, Michel Sarkis, **Guoyu Lu**, “Multi-task Learning for Single Image Depth Estimation and Segmentation Based on Unsupervised Network,” ICRA 2020

Yawen Lu, Yuxing Wang, Devarth Parikh, **Guoyu Lu**, “Extending Single Beam Lidar To Full Resolution By Fusing with Single Image Depth Estimation,” ICPR 2020

Yawen Lu*, Sophia Kourian*, Carl Salvaggio, Chenliang Xu, **Guoyu Lu**, Single Image 3D Vehicle Pose Estimation for Augmented Reality, IEEE Global Conference on Signal and Information Processing (GlobalSIP), 2019 (* indicates equal contribution) (IEEE Student Travel Award) doi: 10.1109/GlobalSIP45357.2019.8969201.

Devarth Parikh, Yawen Lu, Jeff Pelz, **Guoyu Lu**, “Where Am I Looking: Localizing Gaze In Reconstructed 3D Space,” *IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, 2019

Yawen Lu, **Guoyu Lu**, “A Geometric Convolutional Neural Network for 3D Object Detection,” *IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, 2019

Guoyu Lu, “Bring Light to the Night: Classifying Thermal Image via Convolutional Neural Network based on Visible Domain Transformation,” *IEEE Global Conference on Signal and Information Processing (GlobalSIP)*, 2019

David Messinger

Cultural Heritage Imaging

Research

Our research program is largely focused on spectral imaging in two application areas: remote sensing and cultural heritage studies.

Remote Sensing Research

In the remote sensing area we are currently working on algorithms to enhance the spatial resolution of hyperspectral imaging while maintaining accurate radiometry of the resulting imagery. In the cultural heritage imaging area, we are developing novel instrumentation and software systems to lower the barriers to entry for small libraries, museums, and archives to get involved with imaging their collections.

Our project to enhance the spatial resolution of hyperspectral imagery 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. For many applications, individual pixel spectra are compared against either in-scene spectral signatures, or library signatures. Consequently, maintaining radiometric accuracy is a key goal of spatial resolution enhancement of hyperspectral imagery.

To ensure high signal-to-noise ratios, hyperspectral sensors, because of their high spectral resolution, are typically designed to integrate in the spatial dimension, i.e., they have low spatial resolution. Operationally, they are generally used to collect relatively small spatial areas of coverage, and instead are optimized for as high a resolution as possible with small area coverage. If we can develop methods that allow us to successfully sharpen the final imagery, then we may be able to use HSI systems for larger area coverage applications, while maintaining the ability to do targeted, quantitative, exploitation.

To date we have made progress on three aspects of the project, being conducted by three graduate students funded under this effort. First, we have performed an assessment of current state of the art algorithms when they are assessed using per-pixel metrics and target detection results. Next, we have developed a novel algorithm showing promise for sharpening HSI in the visible and near infrared spectral regions using multispectral imagery. Finally, we have conducted an experimental campaign designed to produce datasets for quantitative assessment of sharpening algorithms, without the need for simulation of low resolution imagery.

Figure 1. An experimental campaign designed to produce datasets for quantitative assessment of sharpening algorithms.

Cultural Heritage Imaging Research

Our research in cultural heritage imaging focuses on developing a low-cost, easy to use multispectral imaging system, including software, for use in libraries, archives, or museums. Many research libraries and museums hold unique or rare items on which historically significant text is no longer legible due to damage from water or fire, deterioration, or erasure. Spectral imaging - the process of collecting images of objects in many colors or wavelengths of light, including parts of the electromagnetic spectrum that are not observable by humans but easily imaged by modern sensors (i.e., ultraviolet and infrared) - has become the "go-to" solution for recovering obscured and illegible text on historical materials. Hence, major research libraries are acquiring spectral imaging systems (e.g., the Library of Congress and the Duke University Libraries), and specialized organizations are offering spectral imaging services (e.g., the Center for the Study of Manuscript Cultures at the University of Hamburg, the Lazarus Project and the Early Manuscripts Electronic Library), all in an effort to attract new engagement with archives or special collections that have long sat unused and inaccessible because they are unreadable.

Unfortunately these spectral systems are very expensive, and require significant knowledge of image processing methods to discover the lost text. Most libraries and museums cannot afford such systems, nor do they have the time and knowledge to process the data. To mitigate this, we are developing an end-to-end low-cost spectral imaging system (less than $5000) with limited but significant capabilities. The resulting system will include both the image capture hardware and image processing and visualization software necessary. The spectral bands to be used by the system have been determined by the study of the spectra of several historical documents (parchments and inks).

The proposed spectral imaging system is based on a prototype developed during the 2016 academic year at the Chester F. Carlson Center for Imaging Science (CIS) at the Rochester Institute of Technology (RIT). All system specifications and code will be made freely available. Low barrier-to-entry open source software tools will accompany the system. The prototype imaging system and software will not replace the current systems on the market, but will assist libraries and individual scholars with limited budgets to obtain equipment useful to recover obscured and illegible text in their collections as an introduction to the technology. The system will not be able to resolve all problematic cases, however we believe that the bulk of the spectral imaging work can be completed with the proposed system. The new system will be evaluated from both a scientific perspective by project scientists, as well as a utility perspective by students and scholars involved in museum and library studies.

An early prototype of the proposed system is shown in Figure 2. In this figure, the system does not yet have the colored LED illumination system installed. However, the imaging system will acquire up to 20 spectral images, each at a unique wavelength as determined by narrow-band LED lights. The accompanying software will walk the user through the process of collecting and calibrating the images, and then will perform simple image processing steps on the resulting image cubes. Several visualization tools are being developed, including simple three band false color images and an HTML-based sliding window viewer that is both intuitive to use, and can provide real information to the user.

Figure 2. An early prototype of the proposed system

Publications

T. Kleynhans, **D.W. Messinger**, & J. Delaney, "Automatic material classification of paintings in illuminated manuscripts from VNIR reflectance hyperspectral data cubes", in Proc. SPIE 11392, Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXVI, (April 24, 2020), https://doi.org/10.1117/12.2557890.

S. Huang, **D.W. Messinger**, "Hyperspectral analysis of cultural heritage artifacts: Using modified adaptive coherence estimator to separate spectra with subtle spectral differences", Proc. SPIE 11392, Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXVI, (24 April 2020); https://doi.org/10.1117/12.2558218.

T.R. Peery, **D.W. Messinger**, "Panchromatic sharpening enabling low- intensity imaging of cultural heritage documents," in Proc. SPIE 10980, Image Sensing Technologies: Materials, Devices, Systems, and Applications VI, 1098004 (13 May 2019); doi: 10.1117/12.2518242

R. Ducay, **D.W. Messinger**, "Radiometric assessment of multispectral pansharpening methods as applied to hyperspectral imagery", in Proc. SPIE 11392, Algorithms, Technologies, and Applications for Multispectral and Hyperspectral Imagery XXVI, (May 19, 2020), https://doi.org/10.1117/12.2558741.

A.M.N. Taufique, **D.W. Messinger**, "Hyperspectral pigment analysis of cultural heritage artifacts using the opaque form of Kubelka- Munk theory," in Proc. SPIE 10986, Algorithms, Tech- nologies, and Applications for Multispectral and Hyperspectral Imagery XXV, 1098611 (14 May 2019); doi: 10.1117/12.2518451

Grants

David Messinger, "Low Cost End-to-end Spectral Imaging System for Historical Document Discovery," NEH, $347,680.00

David Messinger, "Radiometrically Accurate Spatial Resolution Enhancement of Spectral Imagery," NGA, $198,306.00

David Messinger, "LASS Research in Sensor and System Modeling," NRO, $595,746.00

Roger Dube, **David Messinger**, "REU Imaging in the Physical Science," NSF, $43,237.79

Jie Qiao

Advanced Optical Fabrication, Instrumentation and Metrology (AOFIM) Lab

Research

Prof. Qiao, Associate Professor, leads the laboratory for Advanced Optical Fabrication, Instrumentation and Metrology (AOFIM) at the Chester F. Carlson Center for Imaging Science. Her research group conduct research in the areas of (1) Ultrafast-Lasers-Based Optical and/or Photonic Fabrication (2) Optical Metrology, Wavefront Sensing and Beam Shaping. Qiao's research is funded by various federal, state and private industries including the National Science Foundation. Dr. Qiao has been inducted to the RIT $1million PI Club in 2020.

During the 2019 academic year, Qiao and her team published three (3) peer reviewed journal papers. Her invited paper titled "Femtosecond Laser Polishing of Germanium towards Freeform Fabrication" was rated as one of the most downloaded papers by Optics Material Express. It was also featured by The Laser Focus World. A patent on this femtosecond laser polishing technology was filed and it is currently pending. Dr. Qiao has provided three invited talks at three (3) national/international conferences. Her team produced a total of five (5) conference publications/ presentations. In addition, Dr. Qiao provided five external invited talks on "Ultrafast Lasers for Photonics Fabrication and/or Optical Differentiation Wavefront Sensing for Freeform Metrology" at four (4) international universities and companies, such as Oxford University (Oxford, UK) and Friedrich Schiller University (Jena Germany).

During the past academic year, Prof. Qiao has received a total of $439,500 new external funding from NSF/IUCRC/ Center for Freeform Optics, NASA, DOE/Lawrence Livermore National Laboratory, NYSTAR Center for Emerging & Innovative Sciences, etc. Dr. Qiao has supported and mentored three (3) PhD students, one (1) undergraduate, and three post-doctoral researchers at the AOFIM lab during the past academic year. Her PhD student Biswa Ranjan Swain received OSA Student Paper Award from OSA, The Optical Society.

Femtosecond Laser Polishing of Optical Material towards Freeform Fabrication

Dr. Qiao and her team have, for the first time, to their knowledge, demonstrated femtosecond-laser-based polishing of Germanium with tunable material removal and maintained the optic-quality surface with roughness of ~1 nm. The controllable material removal with high spatial precision, geometrical flexibility, and optic-quality surface roughness position femtosecond-laser-based polishing as an unprecedented ultraprecision non-contact polishing technique, showing promise for freeform optics fabrication applications. Figure 1 (a) and (b) compare an unprocessed (control) Ge surface and a laser-polished Ge surface generated using 20 polishing passes. It is shown that the control surface contains defects including scratches and discoloration which are not evident in the laser-polished surface. Figure 1(c) further demonstrates that the material removal depth increases from 4 nm to approximately 30 nm when increasing the number of polishing passes from 15 to 100. The optic-quality surface with 1.5 nm RMS roughness is consistently maintained for various material removal depths.

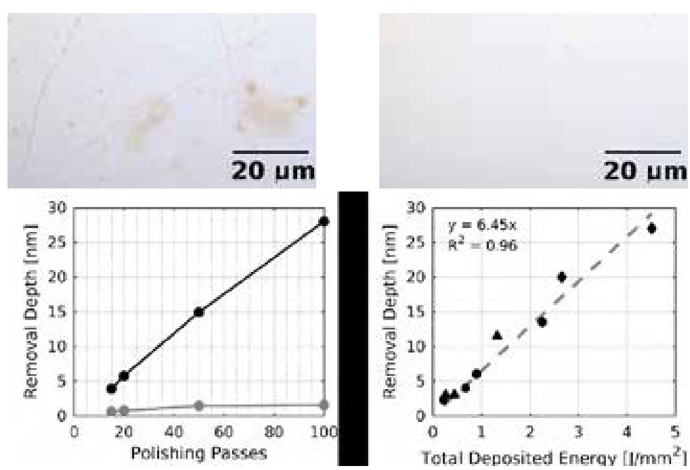


Fig. 1. Optical micrographs within (a) unprocessed and (b) 20-pass laser-polished surface regions; and (c) impact of the number of polishing passes on material removal depth (black) and the resulting root-mean-square surface roughness (gray).

This work has been published in Optics Materials Express as an invited paper ((Optical Materials Express 9 (11), 4165-4177 (2019)) and was rated as the most downloaded paper. It was also highlighted by Laser Focus World.

Waveguide Laser Enabled by Femtosecond-laser Inscription of waveguides in Laser Material

Qiao's research group has demonstrated a waveguide laser enabled by direct femtosecond laser inscription in a Nd:YAG crystal [Crystals, 9 (8), 434 (2019)]. A record low propagation loss of 0.21 dB/cm was consistently achieved for Type II waveguides written by a femtosecond laser. The waveguide laser was further demonstrated with an architecture shown in Fig. 2(a). Fig. 2(b) shows the performance of the waveguide laser. An output power of 26.4 mW at a pump power of 177 mW was achieved. The corresponding slope efficiency and threshold was 21% and 50 mW, respectively. The output power can be scaled up when using a pump laser with higher power. Figure 2 (c) demonstrates a well confined laser mode measured at the output of the waveguide laser. The mode field diameter is 24.8 µm.

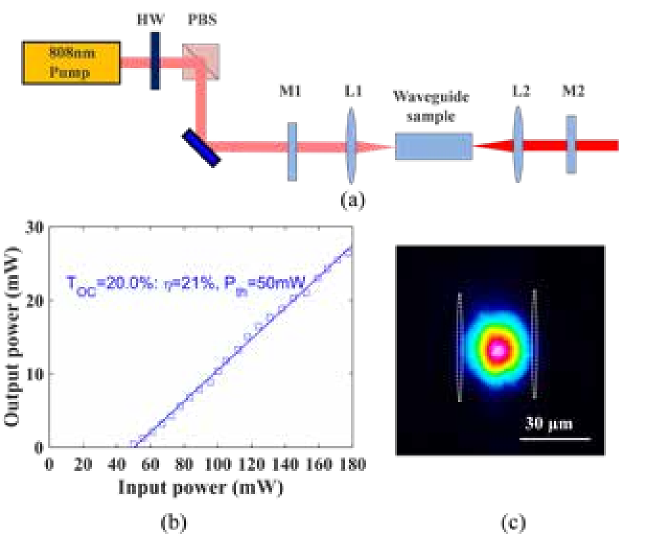


Fig. 2 (a) Schematics of the waveguide laser; M1 and M2 form the laser cavity; (b) output power of the Nd:YAG waveguide laser at 1064 nm vs pump power (c) The profile of the lasing mode (diameter = 24.8 µm)

Femtosecond-laser welding of optical materials for optics integration

Qiao's research group has demonstrated ultrafast laser welding of transparent materials [Opt. Express 28, 31103-31118 (2020)] and glass to metals. They have conducted theoretical modeling and experiment on welding of various glass materials, such as fused silica, BK7 and Borofloat for the application of optics integration and optical packaging with hermetic sealing. The model predicts temperature evolution and internal modifications by incorporating nonlinear absorption and nonlinear electron dynamics, along with temperature dependent thermal properties.

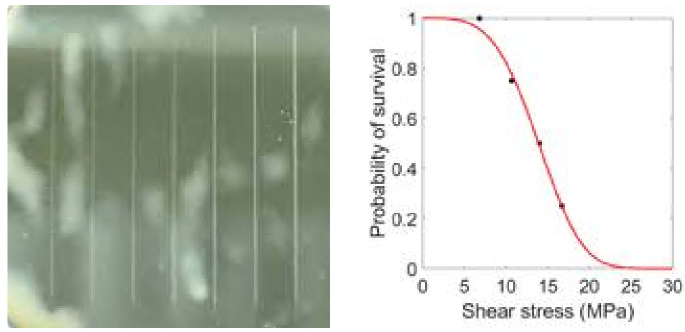


Fig. 3 (a) Welded Borofloat sample showing the parallel weld-seams; (b) Weibull plot for the shear strength test

Based on the modelling predictions, five sets of borofloat substrates have been welded and an example of the welded assembly is shown in Fig.3 (a). The shear strength of the welded Borofloat samples is measured and the Weibull statistical plot is presented in Fig. 3(b). The largest shearing stress that was achieved is 16.7 MPa.

Outreach: Leading WISTEE Connect To Make Global Impact

As a Chair and the Founder of Women in Science, Technology, Engineering and Entrepreneurship (WiSTEE Connect, http://www.wisteeconnect.org), Dr. Jie Qiao organized the Third Global Women of Light Symposium on 15 September 2019 at the first day of the OSA, Frontiers in Optics Conference in Washington DC. The program highlighted a panel and round-table discussions centered on career strategies and intersecting science and entrepreneurship. Professor Qiao provided an introduction on WiSTEE's visions and activities. International Women leaders presented career, entrepreneurial strategies and best practices on promoting emerging women leadership in their respective sectors. A networking session closed out the day and provided an opportunity for informal discussion. The fourth annual symposium was an important opportunity to continue to build a community of women across career ranks and disciplines in STEM and entrepreneurship, creating cross-pollinated best practices and strategies across sectors. Attendees made important professional connections and gain invaluable perspectives on being and supporting women in science, technology, engineering and entrepreneurship.

Graduate and Undergraduate Research Supervised

Biswa Ranjan Swain (Ph.D. Student, RIT, CIS), "Optical Differentiation Wavefront Sensing for High-Dynamic-Range High-Sensitivity Freeform Metrology," Ph.D. Thesis Advisor, June 2018 - present

Lauren Taylor (Ph.D. Student, Female, RIT, CIS), "Ultrafast Lasers for Optics and Photonics Fabrication," Ph.D. Thesis

Advisor, June 2014 – August 2019

Gong Chen (Ph.D. Student, RIT, CIS), "Femtosecond Laser Based Polishing of Glass Materials," Ph.D. Thesis Advisor, June 2019 - present

Manish Sharma (Ph.D. Student, RIT, CIS), "Femtosecond Laser Based Writing of Photonic Devices," Ph.D. Thesis Advisor, June 2019 – December 2019

Publications

B.R. Swain, C. Dorrer, and **J. Qiao**, "High-Dynamic-Range, High-Resolution Freeform Metrology with Optical Differentiation Wavefront Sensing," *Optics Express,* 27 (25), 36297-36310, (2019) https://doi.org/10.1364/OE.27.036297

L. L. Taylor, J. Xu, M. Pomerantz, T. R. Smith, J. C. Lambropoulos, and **J. Qiao**, "Femtosecond Laser Polishing of Germanium towards Freeform Fabrication [Invited]." *Optical Materials Express*, 9 (11), 4165-4177 (2019) https://doi.org/10.1364/OME.9.004165

T. Feng, P. K. Sahoo, F. R. Arteaga-Sierra, C. Dorrer and **J. Qiao**, "Pulse-Propagation Modeling and Experiment for Femtosecond-Laser Writing of Waveguide in Nd:YAG," *Crystals*, 9 (8), 434 (2019) https://doi: 10.3390/cryst9080434

J. Qiao, "Ultrafast-laser-enabled Polishing, Micro-bonding and Waveguide Writing for Photonics Fabrication and Integration," *The 21st International Symposium on Laser Precision Microfabrication*, June 2020

J. Qiao, "Ultrafast Lasers-Based Optical and Photonic Fabrication [Invited]," *2019 Ultrafast Optics XII*, Bol, Croatia, 6–11 October 2019, https://ultrafastoptics2019.org/monday-october-7/

B. R. Swain, C. Dorrer, S. DeFisher, and **J. Qiao**, "High-Dynamic Range, High-Resolution Freeform Metrology with Optical Differentiation Wavefront Sensing," in *Imaging and Applied Optics Congress, OSA Technical Digest (Optical Society of America, 2020)*, paper OF4B.6. https://doi.org/10.1364/AOMS.2020.OF4B.6

P. Sahoo, T. Feng, M. Sharma, G. von Kessel, S. Patra, R, Haque, and **J. Qiao**, "Dynamic modelling for predicting temperature evolution and modification during fs-laser welding of borofloat glass" in *Conference on Lasers and Electro-Optics (CLEO), Applications and Technology, OSA Technical Digest*, Paper ATu3K.2 (2020), https://doi.org/10.1364/CLEO_AT.2020.ATu3K.2

J. Xu, L. Taylor, **J. Qiao**, M. Pomerantz, J. C. Lambropoulos, "Subsurface damage measurement of single crystal germanium and borosilicate glass BK-7," *SPIE Optifab, 2019, Proceedings* Volume 11175,1117508 (2019), Rochester, New York, United States, https://doi.org/10.1117/12.2536691

Patent Pending

Jie Qiao and Lauren Taylor, "Ultrafast-laser-based polishing of optics and additively manufactured parts," Application number: 62/889811.

Grants

"Phase II: Ultrafast laser fabrication of waveguide in laser materials," NASA through Aktiwave LLC, $250,006.60, Feb 7, 2020 – Feb 7, 2022.

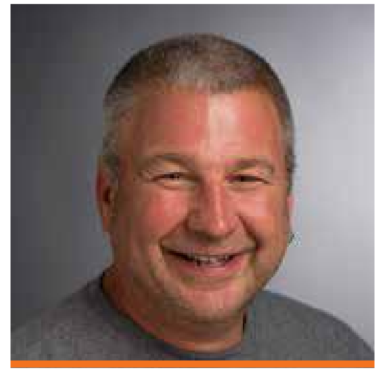
"Ultrafast-laser-based polishing of Glass," NSF, Industry–University Cooperative Research Centers Program, Center for Freeform Optics, $44,009/yr1, January 01, 2020 – December 31, 2020.

"Ultrafast Laser Welding and waveguide inscription for Hermetic Packaging of Nano-implant Chips," Department of Energy / Lawrence Livermore National Lab, $120,000, 11/01/2019 – 9/30/2020.

"Femtosecond laser-based fabrication of photonic waveguides toward waveguide lasers," NYSTAR Center for Emerging & Innovative Sciences (CEIS), $17,692, July 01, 2019 - June 30, 2020.

Carl Salvaggio

Digital Imaging and Remote Sensing (DIRS)



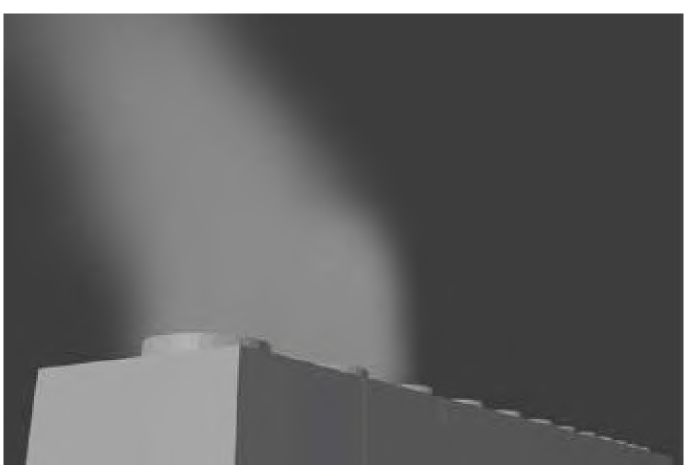
Research

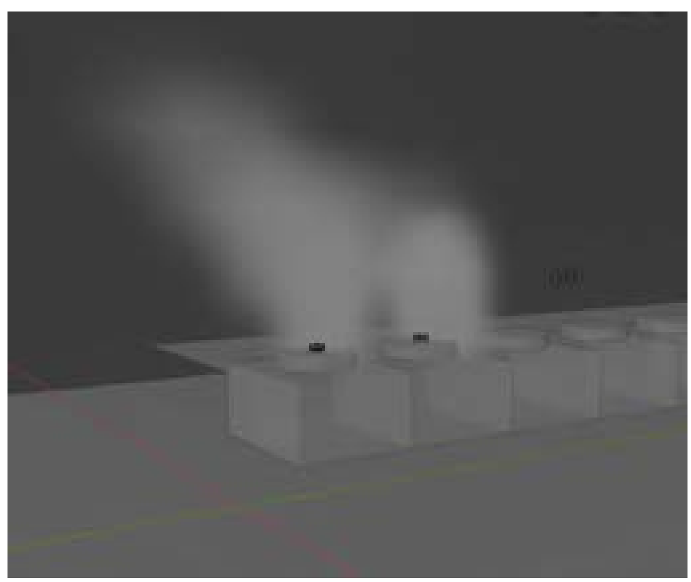
Condensed Water Vapor Plume Volume Estimation

Research Team: Ryan Connal

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. Along with longwave sensors, midwave, shortwave, visible, and near-infrared sensors 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.





Publications

Y. Lu, S. Kourian, **C. Salvaggio**, C. Xu and G. Lu, “Single Image 3D Vehicle Pose Estimation for Augmented Reality,” 2019 IEEE Global Conference on Signal and Information Processing (GlobalSIP), Ottawa, ON, Canada, Nov. 11-14, 2019, pp. 1-5, doi: 10.1109/GlobalSIP45357.2019.8969201.

B.G. Mamaghani, **C. Salvaggio**, “Comparative Study of Panel and Panelless-Based Reflectance Conversion Techniques for Agricultural Remote Sensing,” American Journal of Agricultural Science, Vol. 6, No. 4, Nov. 2019, pp. 40-58.

B. Mamaghani, **C. Salvaggio**, “Multispectral Sensor Calibration and Characterization for sUAS Remote Sensing,” Sensors (Basel), Oct 14, 2019;19(20):4453. doi: 10.3390/s19204453. PMID: 31615104; PMCID: PMC6832506.

Grants

Salvaggio, Carl, “Mechanical Draft Cooling Tower Water Vapor Plume Volume Estimation,” DOE/SRNS, 2/21/2020-2/20/2021 $287,027.00

Grover Swartzlander

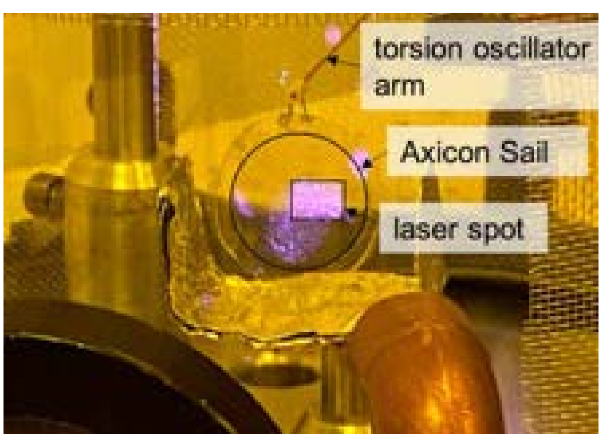
Advanced Optical Concepts Lab

Research

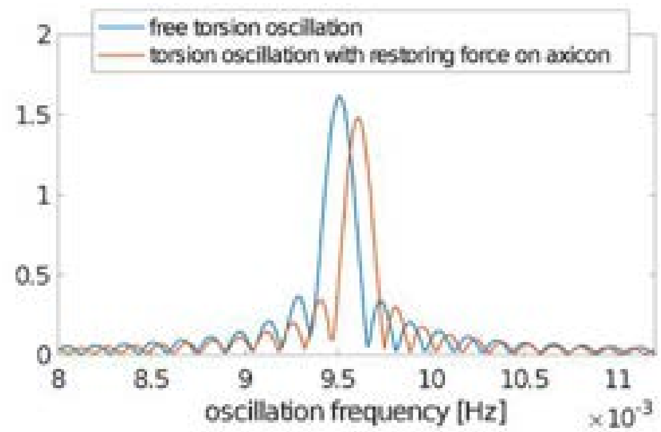
Seeing the unseeable has been a theme of the Swartzlander Group this past year. One branch of this theme involves space travel and going to unseen destinations. The other seeks methods of forming images when exposed to blinding light. These exciting research efforts are funded by NASA, the Breakthrough Foundation, and the Office of Naval Research. Three PhD students (Xiaopeng Peng, Lucy Chu, and Prateek Srivastava), as well as three undergraduate students (Amber Dubill, Joseph Petro, and Lindsey Fiorelli) have served as research assistants on these projects.

Question 1. What is more difficult to observe?

(A) A Black Hole, (B) Gravitational Waves, (C) The North Pole of the Sun. The answer is (C). Neither earth-based nor earth-orbiting telescopes have the correct vantage point. What is more, it is exceedingly expensive to use a conventional rocket to place a spacecraft into a polar orbit around the sun. Nevertheless, heliophysics scientists are eager to observe the poles of the sun where new secrets about stellar dynamics will be revealed. Although rockets alone won't get us there, solar sails can. A solar sail makes use of solar photon momentum, redirecting the sailcraft from an orbit in the ecliptic plane to a solar polar plane. A low mass high area sail could reach a polar orbit in less than a decade. Our team is pioneering a new type of sail based on the physics of diffracted light. RIT has invited a team of solar sailing scientists from the NASA Marshall Space Flight Center (including Les Johnson), Nelson Tabiryan from the manufacturer BEAM Co, and meta-material scientist Margaret Kim from the University of Alabama to collaborate on this effort. Les, Nelson, and Margaret are all co-investigators on the RIT NASA-NIAC award.



Diffractive Beam-Rider. A diffractive axicon laser sail sample from the manufacturer BEAM Co. mounted at the end of the arm of a torsion oscillator. When exposed to a laser beam, the sample moves, centering itself with the laser beam.



Measured oscillation frequency spectrum of an axicon grating, demonstrating a high frequency shift owing to radiation pressure from a 1.75 Watt laser beam.

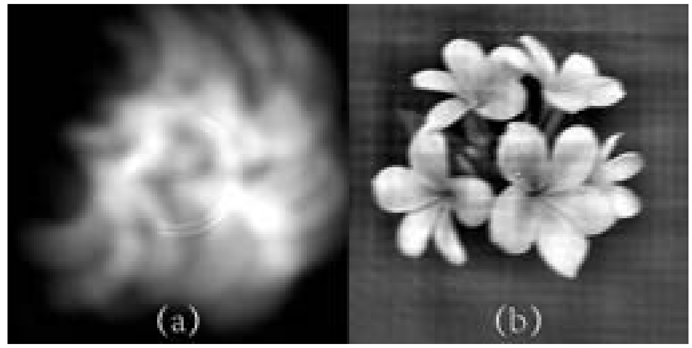
Question 2. What is more difficult to observe?

(A) The Solar Poles, (B) The Weather Patterns on an Earth-Like Exoplanet? The answer is (B). In the best cases to date, so-called exo-earths appear as a dot in a telescope. The Breakthrough Starshot Initiative is exploring the possibility of flying a laser-driven sailcraft past a nearby exoplanet and beaming images back to Earth. A challenge is to keep the sail in the path of the laser beam as it propels forward. Our team is finding solutions to overcome instabilities by use of diffractive laser sails called beam riders. Both our experiments and physics models indicate that this approach is both sound and practical. Rajesh Menon from the University of Utah is assisting RIT on the design and fabrication of such materials.

Question 3. Why don't you shine a laser beam into your cell phone camera?

The answer is you'll damage the imaging sensor array. While the world becomes increasingly dependent on imaging sensors for various applications, the risk of laser damage is a concern that hasn't been adequately resolved for sixty years. Our team examines so-called radiation protection methods that respond instantaneously over a wide range of wavelength. This is accomplished by first diffusing the laser light, then using advanced image reconstruction techniques such as deep learning assisted deconvolution. This effort is a collaboration with Abbie Watnik's team at the US Naval Research Laboratory.

Grover Swartzlander is a Fellow of the Optical Society of America, a NASA NIAC Fellow, a Cottrell Scholar, and an NSF Young Investigator. He served six years as Editor-in-Chief of the Journal of the Optical Society of America - B, and has been a past associate editor for Optics Letters. He has pioneered a number of topics in the field of optics, garnering over 6500 citations for work related to radiation pressure, nonlinear optics, optical vortices, and optical imaging.



Laser Sensor Protection. (a) Optically diffused image degraded by an engineered phase mask, motion blur and sensor noise. (b) Reconstructed image by mean of deep learning assisted deconvolution.

Publications

Y.J.L. Chu, N.V. Tabiryan, **G.A. Swartzlander Jr.**, "Experimental verification of a bigrating beam rider," Physical Review Letters, vol. 123, no. 24, p. 244302, Dec. 13, 2019, https://doi.org/10.1103/PhysRevLett.123.244302 .

J.H. Wirth, A.T. Watnik, **G.A. Swartzlander**, "Half-ring point spread functions," Optics Letters, vol, 45, no. 8, pp. 2179-2182, April 15, 2020, doi: 10.1364/OL.376860.

P.R. Srivastava, Y.J. Chu, **G.A. Swartzlander Jr.**, "Stable diffractive beam rider," Opt. Lett., vol. 44, pp. 3082-3085 June 15, 2019, https://doi.org/10.1364/OL.44.003082.

Grants

Grover Swartzlander, "Diffractive Optic Laser Beam Rider," Breakthrough Prize, $149,802.00

Grover Swartzlander, "Imaging and Laser Beam Effects," Office of Naval Research, $140,679.00

Grover Swartzlander, "Diffractive Lightsails," NASA, $165,558.00

Jan van Aardt

Digital Imaging and Remote Sensing (DIRS)

Research

Dr. Jan van Aardt's laboratory, within the Chester F. Carlson Center for Imaging Science's Digital Imaging and Remote Sensing group (DIRS), focuses on fine-scale remote sensing of vegetation, ranging from forest structure and physiology, to precision agriculture applications. The group's broad research interests thus revolve around spectral (imaging spectroscopy) and structural (light detection and ranging; lidar) remote sensing of vegetation, specifically looking at structure, physiology, and classification challenges. The projects from the past year have included:

i) The use of unmanned aerial systems-based (UAS) imaging spectroscopy, light detection and ranging (lidar), and structure-from-motion (SfM) to assess crop disease risk, harvest maturity, and yield forecasting (NSF-funded; Cornell University collaborators; PhD students Amir Hassanzadeh & Fei Zhang);

ii) Analysis of bidirectional reflectance/transmission distribution functions of forest foliage toward improved radiometric analysis of waveform-lidar (National Ecological Observatory Network; NEON collaborators; PhD student Ben Roth);

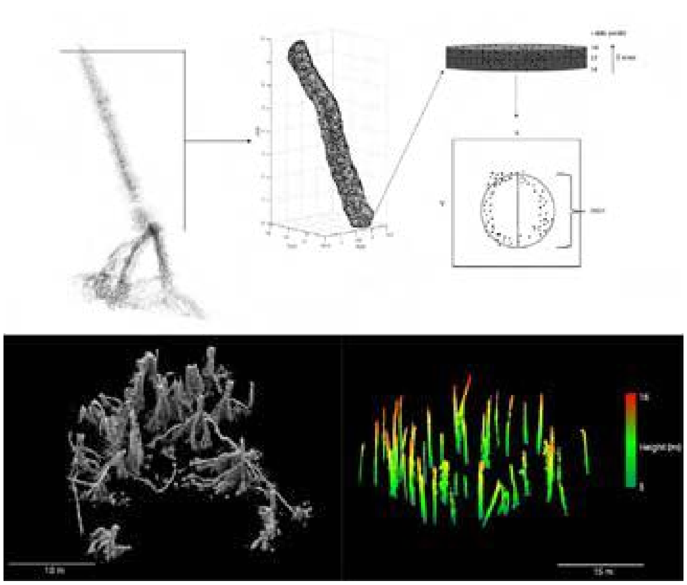


Figure 1. USFS project on mangrove biomass assessment - the use of alpha-shapes to extract a 3D faceted stem structure from a TLS-derived point cloud.

iii) Assessment of mangrove forest sediment elevation changes and vegetation structure, using terrestrial-lidar (Fig. 1) (USFS funded and collaborators; PhD student Ali Rouzbeh-Kargar);

iv) Detection and mapping of duck nest habitats (Fig. 2) (South Dakota State University collaborators; MS student Matthew Helvey);

Figure 2. UAS pilot Tim Bauch collecting early-morning thermal imagery on the prairies of North Dakota for duck nest detection

v) Simulation of corn scenes and remotely sensed data toward specification of future spaceborne missions for corn yield mapping (Fig. 3) (NASA-funded; USDA as collaborators; MS student Grady Saunders);

vi) Optimization of image data inputs for deep learning approaches and extension to change detection (ORNL-funded and collaborators; PhD student Alex Fafard); and

vii) Mapping of beet yield using multi-temporal UAS multispectral imagery (funded by Love Beets; Cornell collaborators; MS student Rob Chancia). Dr. van Aardt serves on various scientific/technical committees, e.g., the National Ecological Observatory Network (NEON) technical working groups on lidar and airborne sampling, conference committees (e.g., the Institute for Electrical and Electronic Engineers' annual International Geoscience and Remote Sensing Symposium; Silvaser conferences), etc.

Figure 3. (left) An actual corn field, collected via RIT's MX-1 UAS platform, showing a multispectral MicaSense image; (right) the same scene, but this time rendered as a simulation in DIRSIG5. 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.

Publications

A. Fafard, **J. van Aardt**, "Global Partitioning Elevation Normalization Applied to Building Footprint Prediction." *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing* 13: 3493 – 3502, June 15, 2020, 10.1109/JSTARS.2020.3002502

A. Hassanzadeh, **J. van Aardt**, S.P. Murphy, S.J. Pethybridge, "Yield modeling of snap bean based on hyperspectral sensing: a greenhouse study," *J. of Applied Remote Sensing*, 14(2), 024519, June 5, 2020, https://doi.org/10.1117/1.JRS.14.024519

B. Roth, M. Saunders, C. Bachmann, and **J. 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: 1761 – 1771, April 2020, 10.1109/JSTARS.2020.2988428.

M.P. McClelland, **J. van Aardt**, 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," *J. of Applied Remote Sensing*, 14(2), 022202, August 9, 2019, https://doi.org/10.1117/1.JRS.14.022202

A. Rouzbeh-Kargar, R. MacKenzie, G.P. Asner, **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), 1791, July 13, 2019, https://doi.org/10.3390/rs11151791.

B. Roth, C. Bachmann, **J. A. van Aardt**, "Deciduous Broad Leaf Bidirectional Scattering Distribution Function (BSDF): Measurements, Modeling, and Effects on Leaf Area Index (LAI) for Forest Ecological Assessments," Poster: *Silvilaser 2019, Conference on Lidar Applications for Assessing and Managing Forest Ecosystems*, Iguazu Fall, Brazil, October 8-10, 2019.

A. Rouzbeh Kargar, R. Mackenzie, **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," Poster presented at *AGU 2019*; December 9-13, 2019; San Francisco, CA, USA.

A. Hassanzadeh, **J.A van Aardt**, S.J. Pethybridge, S. Murphy, "Yield Modelling and Harvest Scheduling of Snap-bean Using Remote Sensing: A Greenhouse Study," Poster presented at *AGU 2019*; December 9-13, 2019; San Fransisco, CA, USA.

Grants

J. van Aardt, A new tool to monitor the resilience of mangroves to sea level rise, USDA, $17,257.00, 5/7/2020 - 12/31/2024

J. van Aardt, Transformation of the New York Table Beet Industry Through Digital Agriculture, Love Beets, $21,407.00, 6/15/2019 - 5/30/2020

J. van Aardt, Accretion assessment in mangrove forests: A comparison between terrestrial laser scanner data from two disparate mangrove forests, USGS, $30,000.00, 10/1/2019 - 9/30/2021

J. van Aardt, Enhanced 3D Sub-Canopy Mapping via Airborne/Spaceborne Full-Waveform LiDAR, NGA, $194,643.00, 8/24/2020 - 8/23/2022

Anthony Vodacek

Digital Imaging and Remote Sensing (DIRS) Lab

Research

Vehicle tracking

Collaborating with Matt Hoffman and Chris Kanan, Vodacek is working on an AFOSR sponsored project to improve tracking of vehicles with remote sensing systems by applying concepts of dynamic data-driven applications systems. This work is currently following two paths. One is leveraging deep learning to improve target recognition and reacquisition. The other is to exploit the DIRSIG image modeling system to dynamically update scenes upon the capture of new data. Both capabilities will enhance the background understanding of vehicle tracking scenarios and direct adaptive sensing so as to adjust to occlusions and dynamic sensing conditions and maintain better tracking.

Natural color image chips (outer images) collected with a hyperspectral camera on the drone platform used to extract reflectance spectra. These reflectance spectra were used by DIRSIG to create a synthetic scene (center image). This methodology is part of the vehicle tracking effort to use DIRSIG for dynamic updating of scene understanding using newly acquired data.

Drone Training in Rwanda

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.

Vodacek contributed to the NASA and USGS Landsat Next spectral expert review for aquatic science. This group of experts reviewed requirements for Landsat Next (future Landsat 10) related to spectral remote sensing of inland aquatic systems. This was done through several virtual meetings. In a similar effort contributing expert knowledge, Vodacek is a member of the Group on Earth Observations (GEO) AquaWatch Focus Group which has held meetings to help define an aquatic reflectance product as part of the Committee on Earth Observation Satellites (CEOS) Analysis Ready Data for Land Framework (CARD4L).

IRES

An NSF-funded International Research Experience for Students in collaboration with Professor Brian Tomaszewski in the School of Interactive Games and Media at RIT was delayed by the pandemic and will take place in a future summer. This international research program is designed to give students a six week summer research experience in GIS and remote sensing analysis for disaster monitoring and assessment in Rwanda.

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

Publications

R.T. Ford and **A. Vodacek**, "Determining improvements in Landsat spectral sampling for inland water quality monitoring." *Science of Remote Sensing*, Volume 1, June 2020, 100005, https://doi.org/10.1016/j.srs.2020.100005

Z. Mulhollan, A. Rangnekar, T. Bauch, M. J. Hoffman and **A. Vodacek**, "Calibrated Vehicle Paint Signatures for Simulating Hyperspectral Imagery," *Proc. of 2020 IEEE/CVF Conference on Computer Vision and Pattern Recognition Workshops (CVPRW)*, Seattle, WA, USA, 2020, pp. 498-506, doi: 10.1109/CVPRW50498.2020.00063.

H. Li, L. Pan, E.J. Lee, Z. Li, M.J. Hoffman, **A. Vodacek**, S.S. Bhattacharyya, "Hyperspectral Video Processing on Resource-Constrained Platforms," *2019 10th Workshop on Hyperspectral Imaging and Signal Processing: Evolution in Remote Sensing (WHISPERS)*, Amsterdam, Netherlands, 2019, pp. 1-5, doi: 10.1109/WHISPERS.2019.8921138.

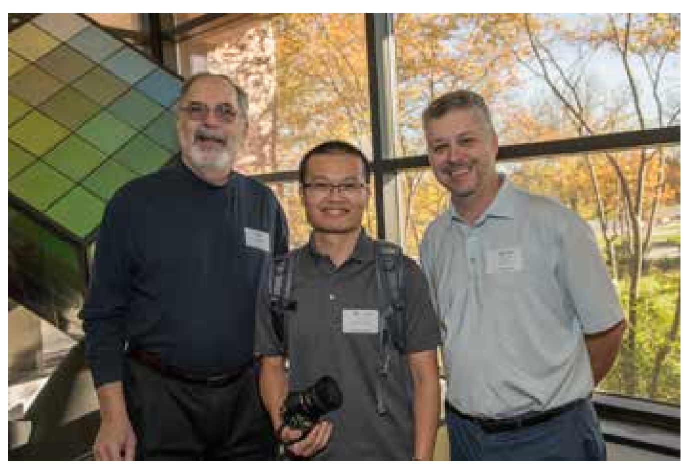
30 Years

The Reunion, October 19, 2019

Open House and Lab Tours











MAGIC

Dinner at Locust Hill Country Club

Faculty

Charles Bachmann

Wiedman Chair
Associate Professor

Gabriel Diaz

Assistant Professor

Roger Easton, Jr.

Professor

James Ferwerda

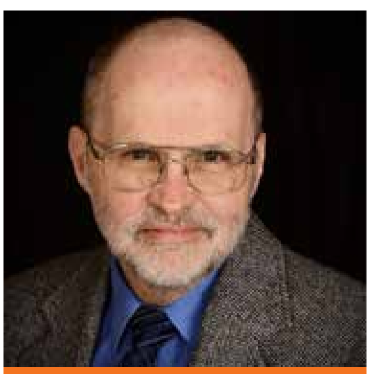
Associate Professor

Michael Gartley

Associate Research
Professor

Aaron Gerace

Assistant Research
Professor



Richard Hailstone

Associate Professor

Maria Helguera

Research Professor

Joseph Hornak

Professor

Emmett Ientilucci

Assistant Professor

Christopher Kanan

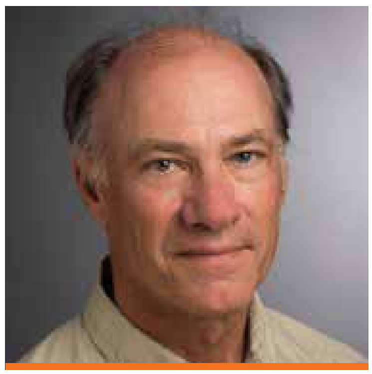
Assistant Professor

Joel Kastner

Professor

John Kerekes

Professor



Robert Kremens

Research Professor

Guoyu Lu

Assistant Professor

David Messinger

Professor

Xerox Chair

Director, Carlson Center for Imaging Science

Zoran Ninkov

Professor

Jeff Pelz

Wiedman Chair

Professor

Jie Qiao
Associate Professor

Navalgund Rao
Research Professor

Carl Salvaggio
Professor

Grover Swartzlander
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Jan van Aardt
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Anthony Vodacek
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Karen Braun

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Matthew Casella

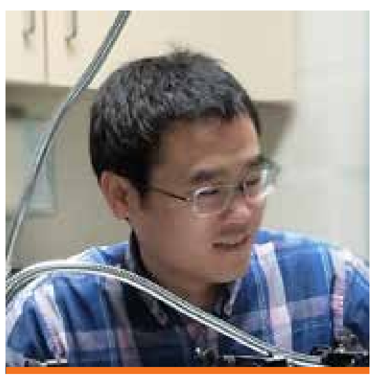
Coordinator of Admin Lab Operations

Byron Eng

Researcher/Engineer I

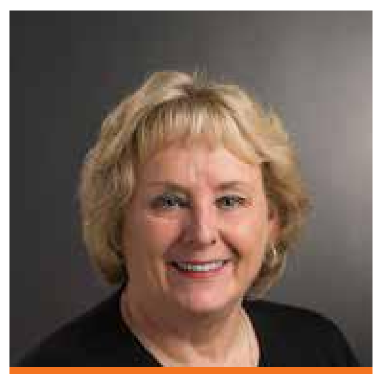
Rehman Eon

Researcher/Engineer II



Tao Feng

Postdoctoral Research Associate



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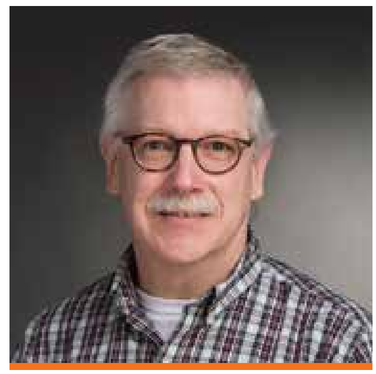
Patricia Lamb
Staff Assistant

Elizabeth Lockwood
Academic Coordinator

Brett Matzke
Research Systems Administrator



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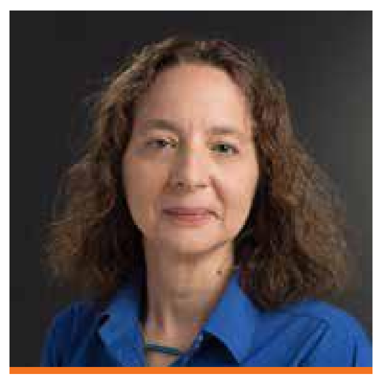
Distinguished Researcher

Colleen McMahon
Research Program Coordinator

Matthew Montanaro
Researcher/Engineer III



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