Table of Contents

5  Foreword

7  Academics
7  Imaging Science Graduate Program
15  Imaging Science Undergraduate Program

21  Research
21  Laboratory for Advanced Optical Fabrication, Instrumentation and Metrology (AOFIM)
27  Magnetic Resonance Laboratory
31  PerForm Laboratory
35  Laboratory for Advanced Instrumentation Research (LAIR)
43  Young Stars and their Planet-Forming Disks
47  Cultural Heritage Imaging
53  Intelligent Vision and Sensing Lab
57  Machine and Neuromorphic Perception Laboratory
61  NanolImaging Research Laboratory
65  Advanced Optical Concepts Laboratory
69  Remote Sensing Laboratory
79  Multidisciplinary Vision Research Laboratory
Foreword

David W. Messinger, Ph.D.
Welcome to the 2018-19 Annual Report of the Chester F. Carlson Center for Imaging Science! This was another exciting year in the Center, with great advances made by our students, faculty, and staff, and we are happy to present them to you in this report.

We do have some sad news to pass along. The Center, as well as the City of Rochester mourned the loss of Catherine Carlson in the Fall of 2018. Catherine was a true supporter of the Center over the past three decades, providing funding for student scholarships and research support. She was also active on campus, always willing to meet with students. Her generosity and spirit will be greatly missed by all of us.

During this past year our Freshman Imaging Project focused on bugs! They built a 3D capture system at the request of the Seneca Park Zoo to collect imagery of insects and convert them into 3D models for display and interaction in virtual environments. The goal was to get a field-deployable system that could virtually bring the insects back to students in Rochester at the zoo. You’ll read more about that in the following pages.

Several of our students and faculty received prestigious awards for their work this past year. Sara Leary ’18 and her advisor, Michael Murdoch, assistant professor of color science, won the Best Poster Award at the ACM Symposium on Applied Perception for her poster titled “Manipulating Object Lightness in Augmented Reality.” The work summarized her senior capstone project research on the optical and perceptual effects of AR overlays on real objects.

Justin Harms ’16 Ph.D. and Charles Bachman, associate professor in the Center, were authors on a paper recognized by SPIE, receiving the Journal of Applied Remote Sensing’s Best Paper Award in the category of Photo-Optical Instrumentation and Design. Similarly, Rinaldo Izzo, an imaging science graduate student, was selected by the chairs of SPIE’s Autonomous Air and Ground Sensing Systems for Agricultural Optimization and Phenotyping as the winner of the Best Paper Award for “An initial analysis of real-time sUAS-based detection of grapevine water status in the Finger Lakes wine country of upstate New York.”

Two Rochester Institute of Technology scientists were recognized by the U.S. Geospatial Intelligence Foundation as some of the tradecraft’s brightest minds for their work on the Landsat 8 satellite. RIT research professor Aaron Gerace and senior scientist Matthew Montanaro were presented with the USGIF Academic Achievement Award at the GEOINT 2019 Symposium in San Antonio, Texas, in June.

Professor John Kerekes applied for and received a very prestigious fellowship to spend the next year advising the U.S. Department of State on issues including its air quality monitoring program and Earth Challenge 2020, the world’s largest ever coordinated citizen science campaign. Professor Kerekes is one of 11 faculty nationwide to be selected for a 2019-2020 Jefferson Science Fellowship.

We also coordinated, along with the Associate Provost of International Education and Global Programs Dr. Jim Myers, a week long imaging session in Dubrovnik, Croatia. Working with faculty at RIT Dubrovnik we brought an imaging system to Croatia and conducted a workshop at the Research Library there, imaging medieval manuscripts and documents. Faculty, staff, and students from the Center participated.

So it was another exciting year in the Center! Next year we are looking forward to celebrating the 30th Anniversary of both the Chester F. Carlson building, as well as the approval of the Ph.D. program in Imaging Science, the first ever Ph.D. program at RIT. I hope you enjoy reading this report and learn about the goings-on in the Center this past year. We look forward to another exciting year. Please stop by the Center whenever you are in the Rochester area!

David W. Messinger, PhD
Director
Overview

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 2018-19 academic year there were a total of 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 the Graduate Laboratory course, normally taken by our first-year graduate students, was revised. 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.

To better prepare our graduate students for the transition that happens at the end of the first year, we have 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 to help students more smoothly transition from a workload dominated by coursework to one more heavily focused on research. While this is only the second year that we have undertaken the re-orientation, we have now made it a permanent part of the schedule since it has proven so beneficial to our students.

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 a year ago. In addition, separately 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.

**Graduate Student Body**

At the beginning of the 2018-2019 academic year, there were 119 graduate students in Imaging Science. Our student population is highly diverse and the incoming graduate student class included international students from 7 countries throughout the world. Our new international student population were: 1 from Canada, 4 from China, 7 from India, 1 from Bangladesh, 1 from Nepal, 1 from South Africa, and 1 from the Phillipines. In total, our incoming graduate student class consisted of 26 students. Of these, 9 students are pursuing the MS degree, with 4 being part-time students, while 17 students are pursuing the Ph.D. degree, with 2 doing so on a part-time basis.

**Student Awards**

Our students continue to receive significant recognition for their accomplishments in widely recognized professional settings:

Mandy Nevins, Microscopy & Microanalysis Student Scholar Award in August 2018, “An Image Restoration Technique for Low Voltage Scanning Electron Microscopy”

Emily Myers, “Monitoring Crop Growth Using UAS and Satellite Imagery” Best Student Oral Paper Award, 2018 IEEE GRSS STRATUS Workshop

Emily Myers, “Monitoring Crop Growth Using UAS and Satellite Imagery” Best Student Oral Paper Award, 2018 IEEE GRSS STRATUS Workshop


**Student, Staff, and Faculty Shared Award (student author underlined)**


**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**

### 2018-19 Refereed Journal Articles

**Chaudhary, A., & Pelz, J. (2019).** “Motion tracking of iris features to detect small eye movements.” *Journal of Eye Movement Research*, 12(6)


**Eon, Rehman; Goldsmith, Sarah; Bachmann, Charles M.; Tyler, Anna C.; Lapszynski, Christopher; Badura, Gregory P.; Osgood, David T.; Brett, Ryan, “Retrieval of salt marsh above-ground biomass from high-spatial resolution, multi-view hyperspectral imagery using PROSAIL,” *Remote Sensing*, 11(11), (2019)


**Han, Sanghui; Kerekes, John P.; Higbee, Shawn; Siegel, Lawrence; Pertica, Alex, “Band selection method for subpixel target detection using only the target reflectance signature,” *Applied Optics*, 58, 11, pp. 2981-2993 (April 10, 2019)


**Jnawali, Kamal; Chinni, B; Dogra, V; Rao, Navalgund, “Automatic Cancer tissue detection using deep learning” - in preparation, (March 2019)


**Swartzlander, Grover A.; Peng, Xiaopeng; Quadrelli, Marco B.; Ruane, Garreth J., “Randomized apertures: high resolution imaging in far field,” *Optics Express*, 25, pp. 18296-18313 (2019)

**Bachmann, Charles M.; Eon, Rehman S.; Lapszynski, Christopher S.; Badura, Gregory P.; Vodacek, Anthony; Hoffman, Matthew J.; McKeown, Donald; Kremens, Robert L.; Richardson, Michael; Bauch, Timothy; Foote, Mark, “A Low-Rate Video Approach to Hyperspectral Imaging of Dynamic Scenes,” *Journal of Imaging*, 5, 1, 6, pp. 1-19 (December 31, 2018)

**Eon, Rehman S.; Bachmann, Charles M.; Gerace, Aaron, “Retrieval of sediment fill factor by inversion of a modified Hapke model applied to sampled HCRF from airborne and satellite imagery,” *Remote Sensing*, 10, 11, pp. 1758-1-23 (November 07, 2018)


**Cui, Zhaoyu; Kerekes, John P., “Impact of Wavelength Shift in Relative Spectral Response at High

Kucer, Michal; Loui, Alex; Messinger, David, “Leveraging Expert Feature Knowledge for Predicting Image Aesthetics,” *IEEE Transactions on Image Processing*, 27, 10, (October 2018)


Selected Conference Proceeding Papers with Graduate Student Authors (student author underlined)


Jnawali, Kamal; Chinni, B; Dogra, V; Rao, Navalgund, “Transfer learning for cancer detection using photoacoustic imaging,” *Proc. of SPIE, Medical Imaging, Computer Aided Diagnosis*: paper no. 10950-140, San Diego, California, United States (March 2019)

Jnawali, Kamal; Chinni, B; Sinha, S; Dogra, V; Rao, Navalgund, “Deep 3D convolutional neural network for automatic cancer tissue detection using multispectral photoacoustic imaging,” *Proc. of SPIE, Medical Imaging, Ultrasonic imaging and tomography*: paper no. 10955-51, San Diego, California, United States (March 2019)

Jnawali, Kamal; Arbabshirana, M R.; Ulhoa, A; Rao, Navalgund; Patel, A A., “Intracranial hemorrhage radiological report classification using CNN and LSTM,” *Proc. of IEEE, ICSC*, Newport Beach, California, United States (March 2019)

Seery, Katherine; Ninkov, Zoran; Horowitz, Jack; Newman, Daniel; Fourspring, Kenneth; Sacco, Andrew; Lee, Paul; McMurry, Craig; Pipher, Judith; Ignotovic, Zeljko; Hassanaliaragh, Moeen, “Characterization of Si-MOSFET CMOS devices for detection at 170 to 250 GHz,” *SPIE Proceedings, Terahertz, RF, Millimeter, and Submillimeter-Wave Technology and Applications Xi*, 10531, 10531R, San Francisco, California, United States (2019)

Vorobiev, Dmitry; Del Hoyo, Javier; Quijada, Manuel; Travinsky, Anton; Raisenan, Alan; Irwin, Alexis; Ninkov, Zoran, “Development of digital micromirror devices (DMDs) for far-UV applications,” *SPIE Proceedings, Advances In Optical And Mechanical Technologies For Telescopes And Instrumentation iii, Advances In Optical And Mechanical Technologies For Telescopes And Instrumentation III*, 10706, 107062F, Austin, Texas, United States (2019)


Donlon, Kevan; Ninkov, Zoran; Baum, Stefi, “Signal dependent interpixel capacitance in hybridized arrays: Simulation, characterization, and
correction,” SPIE Proc, Conference on High Energy, Optical, and Infrared Detectors for Astronomy VIII, 10709, 1070932, Austin, Texas, 2019


Eon, Rehman S.; Goldsmith, Sarah; Lapszynski, Chris; Badura, Gregory; Bachmann, Charles M.; Tyler, Christy; Bauch, Timothy; Osgood, David, Improving accuracy of salt marsh aboveground biomass using high-spatial resolution, multi-view hyperspectral imaging systems, Proceedings of the AGU Fall Meeting, AGU Fall Meeting 2018, December 10-14, 2018, GC009, Washington, District of Columbia, United States (December 10, 2018)

Rouzbeh-Kargar, Ali; Mackenzie, Rich; van Aardt, Jan A., Characterizing Stem Volume in Mangrove Forests Using Terrestrial Lidar Scanning, ForestSat 2018; October 1-5, 2018; College Park, MD, USA, College Park, Maryland, United States (October 2018)

Swartzlander, Grover A.; Chu, Ying-Ju; Srivastava, Prateek, “Beam Riders and Sailcraft Based on Diffractive Light Sails,” Frontiers in Optics, Washington, District of Columbia, United States (September 2018)


Hughes, Ethan; Pethybridge, Sarah; Kikkert, Julie; Salvaggio, Carl; van Aardt, Jan A., “Snap Bean Flowering Detection from UAS Imaging Spectroscopy,” 14th International Conference on Precision Agriculture, Montreal, Canada; June 24-27, 2018., Montreal, Quebec, Canada (June 2018)


Conference Presentations

Ford, Ryan T.; Vodacek, Anthony, “Monitoring cyanobacteria blooms from drone based imaging systems,” IAGLR2018, Harmful Algal Blooms (HABS) and their Toxicity: Remote Sensing and Modeling Approaches, Toronto, Ontario, Canada (June 19, 2018)

Peery, Tyler; Raqueno, Rolando V.; Easton, Roger L., “Useful Metrics for Characterizing Multispectral Systems Used for Cultural Heritage Imaging,” Centre for the Study of
Manuscript Cultures Conference, Hamburg, Germany (June 14, 2018)

Webber, Cody; Kerekes, John P.; Raqueno, Rolando V., “Detecting Enhanced Levels of Atmospheric Methane Using Thermal Infrared Imagery,” IEEE, ATM-MIRS, Newton, Massachusetts, United States (June 2018)

Graduates

The following students received an M.S. in Imaging Science

Nicholas Robert Bitten, Thesis: TIRS-2 and Future Thermal Instrument Band Study and Stray Light Study


Rinaldo Ronnie Izzo, Thesis: Combining hyperspectral imaging and small unmanned aerial systems for grapevine moisture stress assessment

Anjali Kishore Ritu Jogeshwar, Thesis: Tool for the analysis of human interaction with two-dimensional printed imagery

Himaja Mandla, Topic: Mathematics for Deep Learning

The following students received a Ph.D. in Imaging Science

Gregory Patrick Badura, Dissertation: Studies on the Photometric Effect of Roughness, Advisor: Charles Bachmann, Ph.D.


Zhaoyu Cui, Dissertation: System Engineering Analyses for the Study of Future Multispectral Land Imaging Satellite Sensors for Vegetation Monitoring, Advisor: John Kerekes, Ph.D.

Kevan Andrew Donlon, Dissertation: On Interpixel Capacitive Coupling in Hybridized HgCdTe Arrays: Theory, Characterization and Correction, Advisors: Zoran Ninkov, Ph.D. and Stefi Baum, Ph.D.

Ryan T. Ford, Dissertation: Water Quality and Algal Bloom Sensing from Multiple Imaging Platforms, Advisor: Anthony Vodacek, Ph.D.

Sanghui Han, Dissertation: Optimization of Spectral Imaging System Requirements for Subpixel Target Detection Applications, Advisor: John Kerekes, Ph.D.

Zichao Han, Dissertation: The Design and Realization of a Dual Mode Photoacoustic and Ultrasound Imaging Camera, Advisor: Navalgund Rao, Ph.D.

Keegan Sean McCoy, Dissertation: Development, Validation, and Application of a Methodology for the Integration of Optomechanical System Software Models with a Radiative Transfer Image Simulation Model, Advisor: John Kerekes, Ph.D.


Tyler R. Peery, Dissertation: System Design Considerations for a Low-Intensity Hyperspectral Imager of Sensitive Cultural Heritage Manuscripts, Advisor: David Messinger, Ph.D.


Lauren L. Taylor, Dissertation: Ultrafast Laser Polishing for Optical Fabrication, Advisor: Jie Qiao, Ph.D.


Jie Yang, Dissertation: Crime Scene Blood Evidence Detection Using Spectral Imaging, Advisor: David Messinger, Ph.D.

Mohammed Assad Yousefhussien, Dissertation: Deep Learning Methods for 3D Aerial Data, Advisor: Carl Salvaggio, Ph.D.

Chi Zhang, Dissertation: Evolution of A Common Vector Space Approach to Computer Vision Problems, Advisor: Carl Salvaggio, Ph.D.
Xuewen Zhang, *Dissertation: Efficient Nonlinear Dimensionality Reduction for Pixel-wise Classification of Hyperspectral Imagery*, Advisor: Nathan Cahill, Ph.D.

The following are post-graduate plans for some of the students who graduated during 2018-2019

Greg Badura - Research Scientist, Georgia Tech Research Institute EOSL

Chao Zhang - Data mining research assistant, Geisinger Health System

Chi Zhang - Display Color Imaging Engineer, Apple Inc., Cupertino, CA. Design and develop color imaging algorithms to do the OLED panel calibration. Developed a color appearance engine that preserves the image quality and improves the viewing experience across varying types of ambient viewing condition.

Zichao Han – Image Quality Engineer, Magna International, Michigan

Kamran Binaee – Internship, NVIDIA Research

Mohammed Yousef Hussien – GE Computer Vision Lab

Zhaoyu Cui - Sr. Image Scientist, OmniVision Technologies, Inc., Santa Clara, CA

Jie Yang - Staff Engineer, Motorola Mobility, Chicago, Camera phone image quality tuning lead

Mandy Nevins - Research & Development, Optical Engineer (Senior Level) at Sandia National Laboratories in Albuquerque, NM

Rinaldo Izzo - Engineer in the US Air Force in Northern Virginia

Ryan Ford – Penn State

Lauren Taylor – Research Scientist – Optics, Corning Research and Development Corporation (CRDC) in Painted Post, NY. doing fundamental research as part of the Laser Processing Research group within the Applied Optical Physics and Optical Surface Technologies Directorates.

Anton Travinsky – Optical Engineer, Apple Cupertino CA
Academics

Annual Report
Imaging Science
Undergraduate Program

Program Comments by Dr. James Ferwerda

With demand for our graduates growing exponentially, the Center is constantly working to find new and creative ways to increase our enrollments.

This year we started seeing the results of program changes we made with the intent of making it easier for students to transfer into Imaging Science from other majors. Five new students were added to the BS program through the change-of-program initiative enabled last year by offering entry-level courses in both the fall and spring semesters. The following additional steps have been taken over the past year:

- We worked with the Motion Picture Science and Photographic Science programs to leverage commonalities in the first year curriculum
- We undertook a major review/revision of the MCC/RIT 2+2 Imaging Science BS program to reflect curricular changes at both institutions
- We developed a new study abroad pathway to allow Imaging Science students to take a semester abroad and still complete the BS program in four years
- We reviewed and updated inter-institution course articulations to enable/encourage transfer students to the Imaging Science BS program
- The Center’s outreach committee met with RIT’s new VP for admissions and College of Science social media coordinator to enhance the Imaging Science undergraduate program visibility and attract more students.

Looking ahead to the coming year, we will be accepting a pilot group of incoming Photo Science students into the Freshman Imaging Project class. By doing this we will be raising the visibility of the program, and the opportunities in the Imaging Science field, to a new population of students with a clear affinity for imaging systems.

We’re hopeful that these initiatives will result in increased enrollments, and we will continue to seek out other opportunities to attract the best students to the program.
**Freshman Imaging Project**

Cohort Nine of the Freshman Imaging Project class teamed with Rochester’s Seneca Park Zoo to design and build a system to capture and render 3D models of insects. The zoo wanted to include these models in a virtual reality environment that would immerse zoo visitors in a simulation of the jungles of Madagascar. To create the models, the students came up with a system that used 32 modified Raspberry Pi cameras arranged on a hemispherical dome framework to which over 100 feet of LED strip lights had been affixed. The cameras were connected to eight multiplexed Raspberry Pi computers, which were in turn controlled by a single master Pi. Image processing was done by a program called COLMAP, and rendering was done through the use of a web-based service known as Sketchfab. The system was ultimately able to capture and render models showing details as small as one millimeter in approximately two minutes. A student-produced video about the class and their system can be viewed by scanning the QR code shown here.

This was the final time the course was taught by CIS Associate Director, Joe Pow. Joe, who has taught the Freshman Imaging Project class eight years out of the nine it has been offered, retired at the end of 2019. He will spend the fall semester helping the instructor for Cohort 10, Senior Lab Engineer Tim Bauch, come up to speed.

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**Senior Projects**

**3D Detection for Augmented Reality**
Sophia Kourain
Advisor: Professor Guoyu Lu

This paper aims to introduce a novel method for intelligently placing augmented features in a realistic scene. In particular, the algorithm exploits 3D object detection and pose estimation to decide the optimal placement of virtual objects.

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**Devising Standards and Practices for the Utilization of the Vricon Data Suite in DIRSIG**
David Lewis
Advisor: Dr. Michael Gartley

The Digital Imaging and Remote Sensing Image Generation (DIRSIG) model, developed by the Digital Imaging and Remote Sensing Laboratory at the Rochester Institute of Technology, is used to generate synthetic imagery for remote sensing work. It uses OBJ files to geometrically define the scene to be modeled and is capable of modeling sensors from the UV (ultraviolet) end of the spectrum up through the LWIR (long-wave thermal infrared).

The 3D Surface Models delivered by Vricon are typically of large size, with
Vricon reporting “1.5 - 2.0 megabytes per km2” on average. As such, data models such as Indexed 3D Scene Layers (I3S) and Scene Layer Packages (SLPK) have evolved to handle these significant data sets in ways that reduce the memory load on a system being used to view or otherwise handle the data.

The goal of this paper is to create a set of standards and practices for translating Vricon 3D Surface Models into a DIRSIG-friendly format. This will allow laboratories with access to data provided by Vricon to increase the utility of DIRSIG by leveraging high-quality Vricon surfaces to generate synthetic imagery. By creating a standard workflow, consistency between laboratories and groups can be ensured when translating the Vricon data for DIRSIG in an attempt to guarantee not only reproducible results but also an agreed upon level of confidence in the translation within the community.

The OBJ and TIN formats, used by DIRSIG and the Vricon 3D Surface Model respectively, are both designed for pure geometric definition of objects and scenes. While a brute-force conversion of the entire dataset at once is possible, the process would be computationally inefficient. To this end, this paper will also explore the usage of IS3 and SLPK formats to translate portions of a scene as they are asked for by DIRSIG.

**Post-graduation plans:** PhD studies at the University of Burgundy, France

**Yield Modeling With Remote Sensing**

Kevin Kha  
Advisors: Professor Carl Salvaggio, Professor Jan Van Aardt

This study assessed the viability of high spatial resolution imagery with limited spectral band coverage and high temporal resolution to monitor vegetation behavior and generate yield models. The study focused on corn silage grown in two fields across the 2017 and 2018 growing seasons in Livingston County, New York, USA. Between each of these fields and growing seasons there is significant yield variation, as well as yield variation within each field that mandates high spatial resolution imagery. Using vegetation indices as the only independent variable to yield in a simple regression, R-squared values up to 0.69, with RMSE as low as 8.38 Mg ha\(^{-1}\), were observed. The usage of a stepwise regression forward model is also discussed to make considerations for temporally based data that are tracked throughout the growing season. The stepwise regression had adjusted R-squared values up to 0.62 and RMSE as low as 9.22 Mg ha\(^{-1}\) across the four mentioned test cases, with these peak observations being made in the first half of the growing season.

**Post-graduation plans:** Employment at Oculus, Menlo Park, CA

**Modeling an FEL Source-Plaque Setup for Radiometric Calibration of Wide FOV Imaging Systems**

Rachel Shadler  
Advisor: Professor Emmett Lentilucci

The goal of this research project was to present and discuss a new approach to computer-aided modelling of the 0/45 degree lamp-plaque spectral irradiance to radiance transfer method for the calibration of wide field of view imaging systems. The strategy presented qualitatively characterized the method by focusing specifically on accurately modelling the light source shape and characteristics. The resultant four iterations of the lamp were presented and assessed, and the most accurate determined based on comparison to expected provenance. Electron paramagnetic resonance (EPR) spectroscopy is a useful analytical tool for studying objects with cultural heritage significance such as paintings, however it is destructive. Low frequency EPR (LFEPR) spectroscopy has proven useful in the non-destructive identification of specific types of pigments in oil paints on canvas but is unfortunately limited to a canvas less than 30 cm in width. LFEPR using the mobile universal surface explorer (MOUSE) removes this size restriction and can examine very large samples. The goal of this study is to determine if the MOUSE can be used to identify the paramagnetic pigments in a paint mixture on canvas.

**Post-graduation plans:** MS degree program in Optics at the University of Rochester

**Nondestructive Determination of Paint Mixture Composition by EPR Spectroscopy**

Elizabeth Bogart  
Advisor: Professor Joe Hornak

There is a need to analyze paintings with cultural heritage significance to determine authenticity and provenance. Electron paramagnetic resonance (EPR) spectroscopy is a useful analytical tool for studying objects with cultural heritage significance such as paintings, however it is destructive. Low frequency EPR (LFEPR) spectroscopy has proven useful in the non-destructive identification of specific types of pigments in oil paints on canvas but is unfortunately limited to a canvas less than 30 cm in width. LFEPR using the mobile universal surface explorer (MOUSE) removes this size restriction and can examine very large samples. The goal of this study is to determine if the MOUSE can be used to identify the paramagnetic pigments in a paint mixture on canvas.
emittance and irradiance from a NIST calibrated FEL lamp. Less emphasis was placed on plaque behavior, as this was measured and characterized as a 99.9% lambertian surface. Some iterations attempted to improve sensor readout in the model, though these were largely unsuccessful and require further study. The model was validated using a laboratory test set up and was able to predict within surprisingly low ranges of error the illuminance at both the plaque and sensor surface.

**Post-graduation plans**: employment at the Penn State Electro Optics Center, State College, PA

_Soil moisture content (SMC) is essential for drought monitoring, precision agriculture, improving flood modelling accuracy, and various other environmental applications._

Currently, the best methods for determining the moisture content involve more intrusive methodologies, such as large scale moisture networks that monitor many external conditional by using heat dissipation sensors at various depths. However, this is a more intrusive and exhaustive use, which results in a more labor intensive process. Other methods include remote sensing, which typically has three different wavelength types of SMC determination: optical, microwave, and heat. The use of optical remote sensing is becoming crucial for developing new methodologies to predict SMC, as it is non-invasive and significantly less labor intensive. Here, we use a physics-based model to retrieve soil moisture content in the solar domain (350-2500 nm) of the electromagnetic spectrum. The physics based model was based on the Kubelka-Munk radiative transfer theory. The reflectance data was collected using a goniometer system at RIT. Given a broad range of wavelengths available for analyses, several different wavelength combinations were implemented in order to make the determination of which method was more accurate and precise.

**Post-graduation plans**: employment at L3 Harris, Rochester, NY
Laboratory for Advanced Optical Fabrication, Instrumentation and Metrology (AOFIM)

Director: Dr. Jie Qiao

Dr. 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 for advanced optics fabrication including integrated photonics and freeform optics
2. Optical Metrology for phase imaging and wavefront sensing, which can be used for characterizing astronomical telescopes, laser beams or retina imaging.

During the past academic year, Dr. Qiao was appointed as an associate editor for a prestigious journal, Optics Express (by OSA, the Optical Society). She has received a total of $370,000 new external funding from NSF/IUCRC/Center for Freeform Optics, NASA/Aktiwave LLC, DOE/Lawrence Livermore National Laboratory, NYSTAR Center for Emerging & Innovative Sciences, etc. Dr. Qiao worked with Synopsis Inc. (Mountain View, California) and secured donation of four sets of site licenses for optics-and-photonics design software packages. Dr. Qiao has received over $1 million external research funding since she joined RIT in August 2013.

Her team has published two peer-reviewed journal papers, submitted three additional journal manuscripts which are under peer review. Dr. Qiao has provided three invited talks at three national/international conferences, with the most recent one on Femtosecond-Laser-Based Polishing of Optics at the Application Panel on Challenges and perspective on Ultrafast Laser Material Processing, 2019 Laser World of Photonics. Her team produced seven 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 five combined universities, national labs, and companies. During the past academic
year, Dr. Qiao has mentored four PhD students, one undergraduate student, and three post-graduate researchers at the AOFIM lab. Her first PhD student Lauren Taylor defended her PhD thesis and started as a research scientist at Corning Corporation in September 2019.

Dr. Qiao presented “Femtosecond Laser Polishing of Germanium Towards Fabrication of Freeform Optics,” in the 2019 Conference on Lasers and Electro-Optics in San Jose, CA, where she was pleased to discuss with her international colleague Dr. Gérard Mourou, 2018 Nobel Prize Laureate in Physics, who shared the prize with Dr. Donna Strickland. Qiao was the principal investigator for coherent phasing of meter-size grating compressor for realizing the OMEGA EP kilojoule, petawatt laser, enabled by chirped pulse amplification method, co-invented by Mourou and Strickland with whom Qiao has professional interactions at conferences.

Research Highlights

1. Femtosecond Laser Polishing of Germanium 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) shows that the control surface contains defects including scratches and discoloration which are not evident in the laser-polished surface, Fig. 1(b). This research was supported by the NSF I/UCRC Center for Freeform Optics (IIP-1338877 and IIP-1338898) and the FuzeHub, Jeff Lawrence Innovation Fund. This work has been submitted to journal Optics Express for publication.

2. High-Dynamic-Range, High-Resolution Freeform Metrology with Optical Differentiation Wavefront Sensing

There is a need for new strategies and diagnostics for wavefront metrology for freeform optics, owing to the required accuracy, dynamic range, and spatial scale. The optical differentiation wavefront sensor (ODWS) developed by Dr. Qiao and her team allows for wavefront reconstruction from two gradients obtained by applying a spatially varying transmission filter in the far field of the wave under test. The main advantage of ODWS is its adjustable high dynamic range and high resolution. It is novel compared to many other wavefront diagnostics, such as Shack-Hartmann sensor for which the dynamic range is limited by detecting area and resolution limited by lenslets. Qiao’s team has achieved the first successful experimental demonstration of ODWS-based freeform metrology. The demonstrated accuracy and
precision from the measurement of three freeform phase plates are \(-\lambda/10\) and \(-\lambda/50\), respectively. This performance is compared to that of a commercial non-contact coordinate measurement machine based on low-coherence interferometry, showing excellent agreement. This research has broad impact as this work opens the way to further experimental realizations and advantageous application in various optics and lasers related fields, such as optical manufacturing, and in particular freeform optics, adaptive optics and medical imaging such as phase imaging of cells. Figure 3 compares the wavefront measurement of a freeform phase plate, obtained by UltraSurf (based on scanning low-coherence interferometry) and ODWS. The difference of the two measurements shows an accuracy of 0.03\(\lambda\). This ODWS research is funded by the U.S. National Science Foundation. The award number is 1711669. This work has been submitted to Optics Express for publication.

3. Pulse-propagation modelling and experiment for femtosecond-laser writing of waveguide in laser material, Nd:YAG

Unidirectional pulse propagation equation modelling is performed to study the nonlinear laser-mater interaction in silicon and Nd:YAG crystals. The simulation results are validated with reported experimental results for silicon and applied to Nd:YAG crystals with experimental validation. Stress-induced waveguides are written in Nd:YAG crystals using 515-nm, 300-fs pulses at a 1 kHz repetition rate. Waveguides having propagation loss of 0.2 dB/cm are obtained, which is lower than the previous reported values for Type-II waveguides written in Nd:YAG crystals. The results of this project have been submitted to journal Crystals for publication. This research has been partially funded by award 80NSSC18P2148 from the National Aeronautics and Space Administration Small Business Technology Transfer Program (collaborate with Aktiwave LLC).

Outreach: Leading Wistee Connect to Make Global Impact

As a Chair and the Founder of Women in Science, Technology, Engineering and Entrepreneurship (WiSTEE Connect), Dr. Jie Qiao organized the Third Global Women of Light Symposium on September 16, 2018 at the first day of the OSA, Frontiers in Optics Conference in Washington DC. The program was highlighted by a panel and round-table discussions centered on the theme “Career Strategy for Women in Science, Technology, Engineering and Entrepreneurship.” Panelists included Dr. Christie Canaria, director, U.S. National Cancer Institute, SBIR Development Center; Dr. Ulrike Fuchs, vice president, Asphericon GmbH, Germany; Dr. Deborah Goodings, director, U.S. National Science Foundation; and Cathy Long, associate division chief, NASA Goddard Space Flight Center. A workshop on “The Art and Science of Thriving Women” was led by Mary Burkhardt, Lead Peak Performance LLC. Ms. Elizabeth Rogan, CEO of OSA, The Optical Society gave an opening speech on “Advancing Women in Optics;” Dr. Jessie DeAro, Program Director for the ADVANCE Program, gave a keynote speech on “Changing the System Not the People.” A networking session closed out the day and provided an opportunity for informal discussion. A community of women across career ranks and disciplines in STEM and Entrepreneurship continues to be built, creating cross-pollinated best practices and strategies across...
sectors. Career growth, mobility, mentorship, and leadership are collectively developed by this community.

Dr. Qiao will again organize the 4th Global Women of Light Symposium at the beginning of the OSA, Frontiers in Optics Conference in Washington DC on 15 September 2019.

Graduate and Undergraduate Research Supervised


Postdoctoral Researcher and Visiting Scholar Supervised

Tao Feng, Pankaj Sahoo, and Francisco Rodrigo Arteaga Sierra

Journal Publications and Submissions


Presentations/Proceedings/Abstracts/Summaries for 2018 Academic Year (* denotes student co-author)


3. (Invited) J. Qiao, “Differentiating non-thermal ablation and heat accumulation toward ablation-cooled ultrafast-laser processing,” The 19th International Symposium on Laser Precision Microfabrication,


Selected Invited Talks for 2018 Academic Year

1. Friedrich Schiller University Jena, Institute of Applied Physics, Jena, Germany, “Ultrafast Lasers Interactions with Photonic Materials and Optical Differentiation Wavefront Sensing for Freeform Metrology,” July 1, 2019

2. Jabil Corporation, Jena, Germany, “Ultrafast Lasers Interactions with Photonic Materials and Optical Differentiation Wavefront Sensing for Freeform Metrology,” July 1, 2019

3. NASA Goddard Research Center (Laser Branch), Greenbelt, MD, “Ultrafast Lasers for Photonics Fabrication,” February 13, 2019


5. Coherent Corp, San Jose, CA,
Magnetic Resonance Laboratory

Director: Dr. Joseph Hornak

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 and it overcomes the destructive nature of conventional EPR by allowing larger volume samples as a consequence of lowering the operating frequency of the spectrometer from 9 GHz to 150-450 MHz.

Automatic Frequency Control

One shortfall of LFEPR is the lower limit of detection attributed to Boltzmann statistics and the decrease in the operating frequency from 9 GHz to 150-450 MHz. For LFEPR to succeed, the design must maximize signal while minimizing the noise. One common source of noise is baseline drift. This is most often caused by a drift of the resonant frequency of the sample probe relative to the source frequency. When the frequency of the sample probe drifts relative to the operating frequency of the spectrometer due to temperature changes, radio frequency power is reflected from the sample probe. This cause low frequency noise in a spectrum. This past year we designed and implemented an automatic frequency control (AFC) on our spectrometer that keeps the operating frequency of the spectrometer matched to that of the sample probe. To implement this AFC, we needed to rebuild the spectrometer RF bridge. The AFC circuitry is presented in red in Figure 1.

The AFC is based on the principle that the reflected power \( P_R \) and phase \( \varphi \) of the radio frequency (RF) change as the operating frequency of the spectrometer \( f_o \) deviates from the resonant frequency \( f_R \) of the sample probe. Figure 2a presents the absorbed RF power and phase as a function of frequency for a resonant circuit such as the sample probe. The AFC circuit introduces two sidebands at \( \pm 100 \) kHz to either side of \( f_o \). When \( f_o = f_R \) (Fig. 2b) there are equal and opposite in phase components of the sidebands which cancel. When \( f_o < f_R \) (Fig. 2a) the reflected sidebands sum to a positive
value. When fo > fR (Fig. 2c.) the reflected sidebands sum to a negative value. The logic of the AFC code decrements fo if the reflected sideband signals are negative, and increments fo if positive. This process is performed each time a spectral data point is collected or approximately every 0.1 s.

The AFC has improved the limit of detection of the LFEPR. Unfortunately, this has created a new problem. We now are able to see the trace iron impurity in the polyvinyl chloride (PVC) support of the single turn solenoid (STS) sample probe. We have analyzed several potential replacement materials for trace paramagnetic metal content using x-ray fluorescence (XRF) spectroscopy. We plan to solve this problem by replacing the PVC with either a machineable ceramic (MACOR©) by Corning or the polymer polyoxymethylene (Delrin©).

Identifying Pigment Mixtures in Paint

This year we expanded a project to identify pigments in paint on canvas [JAIC 57:73-82 (2018)] to include mixtures of two pigments in paint on canvas. The procedure is capable of identifying pairwise combinations of Egyptian Blue, Ultramarine, Han Blue, Rhodochrosite, Charcoal, and Terracotta Red. Details will be presented in next year’s annual report.

Laboratory Staff

Dr. Joseph Hornak, Professor of Chemistry, Materials Science and Engineering, & Imaging Science in the College of Science at RIT.

Elizabeth Bogart, was an undergraduate Imaging Science student doing her senior research project in the laboratory, graduated with a BS in imaging Science. Her research focused on determining the composition of paints with two pigments.

Jordan Rabideau, a BS Chemistry undergraduate at RIT, joined the laboratory during the summer of 2018. He is evaluating the
automatic frequency control for the LFPR spectrometer.

Dr. Hans Schmitthenner, a Research Scientist in the Center for Imaging Science and Lecturer in the School of Chemistry and Materials Science, is working on targeted contrast agents for magnetic resonance imaging.

Presentations


E.A. Bogart, J.P. Hornak, “Utility of a LFPR MOUSE in Determining Combinations of Oil Paint on Canvas,” 64th Annual Rochester Section of the American Chemical Society Undergraduate Research Symposium, RIT, April 2019.

Publications


Lab director Gabriel Diaz and graduate students have co-authored and published three peer reviewed journal articles – two in the Journal of Vision, and one in Behavior Research Methods. Manuscripts are also currently in review at the IEEE Xplore, and Nature: Scientific Reports.

The 2019 academic year has been a productive one for members of the PerForm Laboratory. Lab director Gabriel Diaz and graduate students have co-authored and published three peer reviewed journal articles: two in the Journal of Vision, and one in Behavior Research Methods. Manuscripts are also currently in review at the IEEE Xplore, and Nature: Scientific Reports. PerForm Lab also had a strong presence at 2019 academic conferences. In May, members of the laboratory were represented as authors or co-authors of six presentations at the Vision Science Society in St Pete's Beach, Florida, the foremost international conference on the study of human vision. Recognition of this work has resulted in several invitations for Dr. Diaz to deliver oral presentations of ongoing work at Vrije University in Amsterdam, at the European Conference on Eye Movements, at the laboratory of Pawan Sinha at MIT, at Giessen University in Germany, and by members of the Facebook Reality Labs to present at the workshop “Eye tracking for VR/AR” at the International Conference of Computer Vision. This spate of productivity is in no small part due to contributions from many talented student members of the laboratory, as is suggested by their own recent successes. Most notably, laboratory member Kamran Binaee successfully defended his dissertation in January, and has since been in Santa Clara, California, where he participated in an internship at the Nvidia’s Corporation. There, Kamran has been helping Dr. Joohwan Kim investigate the consequence of display properties upon the speed and accuracy of visually guided movements in computer simulations.

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.

Work in the area of neuroscience explores the ways in which visually guided movements are fundamentally shaped by constraints that are unique to behavior within the natural visual environment. To study the way in which constraints of the natural environment shape visually guided action, the laboratory leverages emerging display technologies like virtual reality, which allows an immersed participant to make coordinated eye and head movements while interacting with stimuli that move in depth, and while affording parametric control over the visual stimulus, and precise measurement of behavior.
The PerForm Lab is also actively involved in developing methodologies and algorithms that can be used to quantify and characterize behavior within less constrained contexts. Consider that the future of virtual and augmented reality devices is one in which the user’s visual attention is freed from the confines of the traditional 2D display, and that new advances will be required to detect when a user is visually attending to an object or advertisement placed in the 3D environment using eye tracking. However, identifying whether gaze falls upon a region of interest is particularly challenging when the object or observer are in motion, as is most often the case in the natural or simulated 3D environments. This is a challenging problem because the eye-tracking community remains primarily constrained to the context of 2D displays, and has not produced algorithms suitable for the transformation of a 3D gaze position signal into a usable characterization of the subject’s intentions. The PerForm lab recently completed work funded by Google to develop a novel machine learning classification tool that analyzes movements of the head and eyes for the automated classification of coordinated movements, including fixation, pursuit, saccade, whether they arise from movements of the eyes, head, or coordinated movements of both (Fig. 2). This work has benefitted greatly by drawing upon the technical strengths of local collaborators and graduate students at the Chester F. Carlson Center for Imaging Science.

Another applied project aims to modify a popular open-source eye tracking framework made by Pupil Labs which, if improved, could revolutionize the use of eye tracking in both laboratories and industrial contexts. Although Pupil Labs markets an affordable, open-source solution for eye tracking, preliminary interaction with the Pupil Labs HMD integration revealed frequent track-loss when the eye was oriented towards the upper third of the display, and when the eye was rotated away from the cameras placed below the display optics (Fig. 3A). This camera placement is symptomatic of a lack of space between the optics and the face. Therefore, our first goal is to modify the hardware so that the large 120 Hz cameras are replaced with compact 240 Hz cameras small enough to be mounted inside the HMD, behind the optics, and integrated within the optical pathway of the HMD, providing high-quality, on-axis views of the subject’s eyes (Fig. 3B).

Figure 1, A: To test the role of visual tracking behavior in supporting accurate placement of the hand/paddle when catching, subjects were immersed in a virtual reality simulation with an integrated eye tracker, and tasked with catching virtual balls projected along parameterized trajectories. B: The experimenter’s desktop view of what the subject saw inside the VR display. The lines receding in the depth represents the face of the motion-tracked paddle, on which can also be seen the red virtual ball.

Figure 2, A: Estimates of sensed eye and head orientation in terms of azimuth and elevation (Az, El) were collected during the performance of coordinating the natural tasks. The custom sensor suit included a spatially aligned and temporarily synchronized combination of Pupil Labs mobile eye tracker, a head-mounted inertial measurement unit (IMU), and a ZED RGB-D stereo camera.

Figure 2, B: A team of trained RIT undergraduates used custom Matlab software to label gaze events embedded within the eye and head velocity signals, such as fixation upon a stable world object, or saccades between locations in the visual environment. These labels were later used to train a supervised learning algorithm for the automatic classification of gaze events.

PerForM labs is also invested in clinical research that promises to improve health related outcomes for those suffering from blindness as a result of stroke. Over the last 10 years, the Huxlin laboratory at the University of Rochester has developed new methods for visual rehabilitation,
and they have been shown to locally recover a range of visual abilities in previously cortically blind (CB) fields. Work being conducted at the PerForm Labs, and in collaboration with Dr. Huxlin, will leverage recent advances in eye tracking and virtual reality technology to improve the effectiveness of these methods for visual rehabilitation after stroke. Hardware and software development will be followed by replications of published psychophysical experiments conducted with traditional desktop displays, and quantitative comparisons will be used to assess the effectiveness of the novel apparatus (Fig. 4).

Figure 4. Virtual reality rehabilitation task. A: Trial sequence for the global, left-right, direction discrimination task used to collect preliminary data. A 100 ms period of enforced fixation is followed by a brief presentation of an ambiguous motion stimulus. The subject's task is to indicate perceived motion direction. Task difficulty is modulated by systematic manipulation of the "direction range" of dot motion. B: A representation of the view inside the VR head mounted display during data collection. The experimenter’s view is shown in the lower left inset. Red spheres represent eye locations, red line and right/left gaze vector, and blue line the cyclopean gaze vector. C: Discrimination performance vs direction range for a single subject, single session. The dotted line represents the 75% discrimination threshold. D: Threshold direction range for a single subject over nine sessions completed on consecutive days shows improvement with practice.

Figure 3. Pupil Labs eye tracker integration into the HTC Vive. (3A) The current Pupil labs integration has sub-optimal placement of the cameras in the periphery. (3B) The proposed design moves the eye cameras inside the HMD. Mirrors that reflect light in the near infrared, but not visible range, will provide the eye cameras with a high quality, on-axis view of the subject’s eyes.
Laboratory for Advanced Instrumentation Research (LAIR)

The Laboratory for Advanced Instrumentation Research is dedicated to;

(a) the development of novel and innovative instruments for gathering data from a wide variety of physical phenomena

(b) the training of the next generation of instrument scientists who will occupy positions in government, industry and academia.

LAIR utilizes the excellent infrastructure facilities available at RIT including the Semiconductor and Microsystems Fabrication Laboratory, the Center for Electronics Manufacturing and Assembly, and the Center for Detectors.

A wide variety of instruments have been developed at RIT over the last twenty years including digital radiography systems, liquid crystal filter based imaging systems for airborne (UAV) mine detection, a speckle imaging camera for the WIYN 3.6 meter telescope, a MEMS digital micromirror based multi-object spectrometer, and an X-ray imaging systems for laser fusion research. This research has been funded by NASA, the NSF, NYSTAR and a variety of corporations such as Exelis, ITT, Kodak, Harris, Moxtek and ThermoFisher Scientific.
1. Studies of the optical properties of TI DMDs and the development of a multi-object spectrometer

The Digital Micromirror Device (DMD) built by Texas Instruments is the device used as the optical slit mask in the RITMOS Multi-Object Spectrometer. RITMOS was designed to record the spectra of multiple stars within the field of view. The instrument has been improved, with newly written software and a new imaging camera. The 2010 Astronomy Decadal survey’s leading suggestion for space instrumentation is a wide field IR Space Telescope which will require a multi-object spectrograph to accomplish its science goals. Other space-based missions requiring multi-object spectroscopy capability have been proposed, including for the ultraviolet (e.g. LUVOIR). There have been four key aspects of the performance of DMDs that have been questioned for use in a MOS for space. We have attempted to address each of these in the work carried out in LAIR.

1. To assess the light scattering and reflectance properties of DMDs in a spectrograph configuration, an optical test set-up has been assembled. The test set-up is designed to simulate the performance of the a DMD in a typical multi-object spectrograph (MOS) configuration. In a MOS, individual micromirrors are selected and turned to the on-state to reflect light to a spectrograph. All other micromirrors are turned to the off-state, away from the spectrograph. Light scattered from DMD mirrors in the off-state can contaminate the measured spectra.

2. For use in the infrared, it is required that DMDs operate at cooled temperatures. The testing cohas shown that normal operation of these devices was able to be carried out to a temperature of near 77K. This was the limit of how cold the DMD could be cooled by the test configuration and did not reflect a failure of the DMD.

3. Radiation hardness of the DMD. Heavy ion and high energy proton testing of DMDs has been previously performed. Gamma radiation testing of DMDs was performed to determine the viability of the devices in the space radiation environment. Testing was performed at the NASA Goddard Space Flight Center’s Radiation Effects Facility. The devices were found to tolerate the total-ionizing dose expected for a typical 4-year mission at an L2 orbit.

4. The DMDs are supplied by Texas Instruments with a protective borosilicate glass window. This glass limits the range of wavelengths that the device can be used for. We have developed a technique for removing these windows and repacking the devices with windows that are transmissive in the ultraviolet and infrared. Initially we have used magnesium fluoride and HEM Sapphire as the replacement window material. These devices have been successfully shake/shock/vibration tested at the NASA GSFC facility for verification of ability to survive a launch.

Figure 1: Marty Carts (NASA), Lexi Irwin (PhD student), Kate Oram (PhD student), Zoran Ninkov (RIT), Tony Chapman (Thermo), Dmitry Vorobiev (CU/RIT), Eugene Gerashchenko (NASA) at the Gamma Testing facility at NASA GSFC.

2. Enhancing Focal Plane Array Quantum Efficiency with Quantum Dots

There are many interesting things to see in the ultraviolet (UV). Lithography for integrated circuit production is exposed with 193nm light with future, honey bees’ view of flowers include the UV region and analytical instruments use UV emissions to identify materials. Current silicon CMOS or CCD based detectors used in standard digital cameras do a poor job of recording UV images. The ability to detect UV light may be improved by switching to exotic materials or by polishing the detector until it is so thin that it is flexible and almost transparent. Both of those options are very expensive to fabricate. A different approach is to apply a coating of nanometer-scale materials to the surface of a detector chip to convert the incoming UV light...
is to visible light which is more readily recorded by standard detector chips. We use an inkjet printer to deposit the quantum dots. This research has developed a method of coating detector arrays with nano materials and applied it to improve the ability of detectors to record UV and blue light.

Figure 2: Quantum Dot coated detector in aluminum mask under UV illumination. The active area is 15mmx15mm

3. Detector Characterization

The effect of interpixel capacitance (IPC) on images captured by infrared sensors was first identified by a PhD student at RIT, Drew Moore. Now that this effect has been characterized, research has focused on investigating how IPC affects photometry. IPC acts as a smoothing filter, by spreading out the signal of each pixel into the neighboring pixels and also affects the normal assumptions about the relationship between noise and signal. Astronomers commonly use a method of photometry called aperture photometry which is compromised by IPC effects. For isolated stars the effect is small. Continuing research will explore IPC effects on diffraction limited imagery, such as on the James Webb Space Telescope, as well as in crowded fields. In addition we have been modeling the source of IPC namely the fringing fields between pixels using the Lumerical Device software. We are currently working to characterize the ThermoFisher CID821 based imaging system. This camera is of interest because of its high dynamic range, random addressability, and ability to perform non-destructive readouts. This is the first CID array that has been back thinned for enhanced blue sensitivity. We will eventually use the CID for extremely high contrast ratio imaging of faint sources around bright stars.

Figure 3: The cartoon concept of IPC in a detector array.

37

4. Imaging Polarimetry

Imaging polarimeters utilizing the division-of-focal technique present unique challenges during the data reduction process. Because an image is formed directly on the polarizing optic, each pixel “sees” a different part of the scene; this problem is analogous to the challenges in color restoration that arise with the use of Bayer filters.

Although polarization is an inherent property of light, the vast majority of light sensors (including bolometers, semiconductor devices and photographic emulsions) are only able to measure the intensity of incident radiation. A polarimeter measures the polarization of the electromagnetic field by converting differences in polarization into differences in intensity. The microgrid polarizer array (MGPA) divides the focal plane into an array of superpixels. Each sub-pixel samples the electric field along a different direction, polarizing the light that passes through it and modulating the intensity according to the polarization of the light and the orientation of the polarizer. We are actively looking at techniques for hybridizing microgrid polarizer arrays to commercial CID, CCD and CMOS arrays.

We had the opportunity to deploy one of these polarization cameras to the CTIO 1 meter telescope in Chile, South America. Below is an image of Saturn obtained from that data revealing the polarization signature.
5. THz Imaging

A silicon CMOS based array purposed for the terahertz regime has promising applications for many fields including security screening, manufacturing process monitoring, communications, and medicine. Current systems mainly consist of bulky technology, including large pulsed laser systems and are primarily laboratory based setups. A silicon CMOS based technology was chosen in order to eventually develop a compact, portable, practical imaging system. A large amount of recent research has been conducted regarding the detection of terahertz using silicon MOSFETs. The THz focal plane technology being tested is uncooled and employs direct overdamped, plasmonic detection with silicon CMOS MOSFETs that are each coupled to an individual micro-antennae.

Figure 6: A photo of experimental THz scanner setup is shown above. The source is on the left, followed by the Teflon lens, and the test dewar enclosure on the right. The thor lab box, containing various targets, is mounted on XYZ and rotation stages for scanning.

6. Chip Description

The chip used in these experiments was a custom designed and fabricated in a 0.35 μm silicon CMOS process using the MOSIS facility. On the chip is a test imaging array and fifteen test transistors. These ‘test’ transistors can be connected directly to outputs for characterization without clocking electronics. Our work has focused on characterizing the response from these five test transistors. The figure below shows a micrograph of the test chip with the test transistors located on the bottom edge.

Figure 7: Generation II MOSIS THz devices. Fifteen test structures are seen along the edges.

Test Description

The transistors were biased using SRS power supplies which connect to the test enclosure via low noise shielded twisted pair cables. The enclosure creates a Faraday cage around the fan-out board and test chip, and the connections are fed through the box with feed-through capacitors to reduce as much RF noise as possible. A removable high resistivity silicon window on the front of the enclosure precedes a high speed shutter which is controlled via digital I/O. The enclosure is mounted on XYZ and rotation stages for alignment purposes. A SRS 560 current preamplifier is commanded via a MATLAB serial interface for applying bias sweeps and relaying data. The radiation source is a 200-300 GHz tunable source from Virginia Diodes.

Sample Publications

1. Direct measurement of the Kepler Space Telescope
   CCD’s intra-pixel response function
   Vorobiev, D., Irwin A., Ninkov Z., Donlon K., Caldwell D., Mochnacki S. [2019]

2. Interpixel Capacitive Coupling in Hybridized Arrays

3. ATLAS probe: Breakthrough science of galaxy evolution, cosmology, Milky Way, and the Solar System

4. Evaluation of Tunable Pixel-
scale Fabry-Perot Etalons for Optical Imaging

5. Using quantum dots in a sol-gel matrix to enable deep-UV sensitivity for standard silicon based imaging detectors

6. The effects of gamma radiation on digital micromirror devices

7. Direct measurement of the intra-pixel response function of the Kepler Space Telescope’s CCDs

8. ATLAS probe for the study of galaxy evolution with 300,000,000 galaxy spectra
Content, R.; Wang, Y.; Roberto, M.; Dickinson, M. Ferguson, H.; Hillenbrand, L.; Fraser, W.; Behroozi, P.; Brinchmann, J.; Cimatti, A.; Daddi, E.; Hirata, Christopher; Hudson, Michael; Kirkpatrick, J. Davey; Barkhouser, Robert; Bartlett, James; Benjamin, Robert; Chary, Ranga; Conroy, Charlie; Donahue, Megan; Doré, Olivier; Eisenhardt, Peter; Glazebrook, Karl; Helou, George; Malhotra, Sangeeta; Moscardini, Lauro; Ninkov, Zoran; Orsi, Alvaro; Ressler, Michael; Rhoads, James; Rhodes, Jason; Shapley, Alice; Smee, Stephen [2018] Proceedings of SPIE - The International Society for Optical Engineering, v10698, p 106980J (14 pp.)

9. Signal dependent interpixel capacitance in hybridized arrays: simulation, characterization, and correction

10. ATLAS probe for the study of galaxy evolution with 300,000,000 galaxy spectra
Content, R.; Wang, Y.; Roberto, M.; Dickinson, M. Ferguson, H.; Hillenbrand, L.; Fraser, W.; Behroozi, P.; Brinchmann, J.; Cimatti, A.; Daddi, E.; Hirata, Christopher; Hudson, Michael; Kirkpatrick, J. Davey; Barkhouser, Robert; Bartlett, James; Benjamin, Robert; Chary, Ranga; Conroy, Charlie; Donahue, Megan; Doré, Olivier; Eisenhardt, Peter; Glazebrook, Karl; Helou, George; Malhotra, Sangeeta; Moscardini, Lauro; Ninkov, Zoran; Orsi, Alvaro; Ressler, Michael; Rhoads, James; Rhodes, Jason; Shapley, Alice; Smee, Stephen [2018] Proceedings of SPIE - The International Society for Optical Engineering, v10698, p 106980I (15 pp.)

11. Development of digital micromirror devices (DMDs) for far-UV applications

12. On-sky performance evaluation of RITMOS, a
13. The opto-mechanical design of SAMOS: a DMD-based spectrograph for the SOAR telescope

14. Point-spread Function Ramifications and Deconvolution of a Signal Dependent Blur Kernel Due to Interpixel Capacitive Coupling

15. Characterization of Si-MOSFET CMOS devices for detection at 170 to 250 GHz

16. Astronomical Polarimetry with the RIT Polarization Imaging Camera

Overall DMDs are extremely robust and promise to provide a reliable alternative to microsutter arrays to be used in space as remotely programmable slit masks for MOS design.

Multiobject spectrometers (MOSs) have benefitted from the use of digital micromirror devices (DMDs) as programmable slit masks in ground-based applications because of the high reliability and accuracy DMDs provide. For this reason, knowing how DMDs would perform under conditions associated with space deployment would benefit astronomers looking for slit masks to use in MOSs on space missions.

A collaboration between Rochester Institute of Technology (Chester F. Carlson Center for Imaging Science & Department of Manufacturing and Mechanical Engineering Technology), NASA Goddard Space Flight Center, Space Telescope Science Institute and Johns Hopkins University (Department of Physics and Astronomy & Department of Mechanical Engineering) evaluated the feasibility of using DMDs in space applications. A series of tests were performed to investigate the performance of DMDs under conditions associated with space deployment to determine their suitability for multiobject spectrometers on space missions.

Space-based MOSs would encounter the same vibration and mechanical shock that is typically associated with any launch into space, so the DMDs were subjected to vibration and shock testing. DMDs underwent vibration testing while powered off as well as in the powered on and operational state. The project utilized Texas Instruments’ DLP7000 .7” XGA DMDs controlled using the DLi4120 Development Kit in order to test the DMDs in two different operating modes; holding a steady pattern and quickly switching among several patterns. The team then inspected the DMDs for pixels that may have changed the direction of the tilt of the micromirrors and did not detect any pixels that changed state after the vibration testing.

The DMDs were also exposed to thermal cycling and low temperature testing to determine lifetime and performance at cryogenic temperature. Among several tests conducted, the DMD micromirror array was subject to an accelerated lifetime test, where it was...
cycled between the on and off state for 200,000 flips – an approximation of a 10 year life of a MOS using DMD technology. Among this and the other tests conducted, the results indicated that DMDs are insensitive to low temperatures, and able to operate at temperatures as low as 78 K. Two separate experiments focused on the result of accelerated heavy-ion radiation on DMD reliability. The DMDs were exposed to heavy-ion radiation above realistic levels for fluxes, and did not obtain any permanent damage or experience hard failure. All micromirrors that were initially disrupted from testing were cleared with the loading of a new pattern on to the DMDs, allowing the team to conclude that DMDs have limited sensitivity to heavy-ion radiation.

The combined assessment of radiation, vibration, mechanical shock and temperature testing of DMDs allowed the team to determine that DMDs are extremely reliable and robust. Overall, the results confirm that DMDs are suitable for use in both ground-based and space-based multiobject spectrometry.

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**Graduate Students 2018-19**

Kevan Donlan (CIS)
Katie Seery (AST)
Ross Robinson (CIS)
Kyle Ryan (CIS)
Alexis Irwin (AST)
Kate Oram (CIS)
Anton Travinsky (CIS)
Daniel Edwards (CIS)
Lucas Black (Manufacturing and Mechanical Systems Integration)

**Undergraduate Students 2018-19**

Robert Ichiyama (Chemistry)
Alexander Knowles (Chemistry)
Tullio Geraci (Chemistry)

**REU student (2018-19)**

Gavin LaRue (Rose Hulman)

**Post-Doctoral Fellow**

Dmitry Vorobiev (AST - graduated)

**Co-Op Student**

Jonathan Hoover (Computer Science)
Young Stars and their Planet-Forming Disks

Director: Dr. Joel Kastner

CIS faculty member Joel Kastner and his RIT students are exploiting the recently commissioned Atacama Large Millimeter Array (ALMA) radio interferometer as well as the latest generation of adaptive optics (AO) cameras on the world’s largest (8-meter-class) optical/infrared telescopes to make advances in the study of protoplanetary disks.

Thousands of extrasolar planets (“exoplanets”) have been discovered over the past two decades. Astronomers seeking to understand the astonishing variety of planetary masses and orbital separations that characterize these myriad exoplanet systems, as well as the earliest evolution of our own solar system, must carefully study exoplanet birthplaces: dusty, molecule-rich protoplanetary disks orbiting young stars. CIS faculty member Joel Kastner and his RIT students are exploiting the recently commissioned Atacama Large Millimeter Array (ALMA) radio interferometer as well as the latest generation of adaptive optics (AO) cameras on the world’s largest (8-meter-class) optical/infrared telescopes to make advances in the study of protoplanetary disks.

A prime example is the “library” of subarcsecond-resolution ALMA molecular emission images of the nearby, young, close binary system V4046 Sagittarii that was recently assembled, analyzed, and published by Kastner, RIT AST graduate student Annie Dickson-Vandervelde, and collaborators (Kastner et al. 2018, Astrophysical J., 863, 106). V4046 Sgr is a binary T Tauri system of age ~20 Myr that lies just 72.4 pc from Earth. The ALMA observations were obtained in the 1.1–1.4 mm wavelength range with antenna configurations involving maximum baselines of several hundred meters, yielding subarcsecond-resolution images in more than a dozen molecular species and isotopologues (Fig. 1). This ALMA image library of V4046 Sgr hence elucidates, on linear size scales of ~30–40 au, the chemical structure of the evolved, protoplanetary disk orbiting the close (2.4 day period) binary system. This study of the “molecular anatomy” of the circumbinary disk orbiting V4046 Sgr should serve as motivation for additional subarcsecond ALMA molecular line imaging surveys of nearby, evolved protoplanetary disks aimed at addressing major uncertainties in protoplanetary disk physical and chemical structure and molecular production pathways.

In another new ALMA-based paper on V4046 Sgr, CIS postdoc Dary Ruiz-Rodriguez, supervisor Kastner, and team present and analyze the highest-
resolution continuum and scattered-light images obtained to date of this circumbinary disk (Ruiz-Rodriguez, Kastner, et al. 2019, Astronomical Journal, 157, 237). Ruiz-Rodriguez et al. observed the disk with ALMA at 870 μm (Band 7) during Cycle 4, and analyzed these data in conjunction with archival H band polarimetric images taken with SPHERE/IRDIS on the ESO Very Large Telescope. They investigated whether the ring structures detected in these images can be accounted for by models that combine two-dimensional two-fluid (gas + particle) hydrodynamical calculations with three-dimensional Monte Carlo radiative transfer simulations to simultaneously model the potential observational signatures of protoplanet-induced gaps at millimeter and near-infrared wavelengths. Ruiz-Rodriguez et al. find that a single planet with a mass in the range between 0.3 and 1.5 MJ orbiting at 20 au from the central star can well reproduce the combination of a deep gap in scattered light and a surrounding bright 870 μm ring. These results represent perhaps the best present constraints on the mass of a putative (as-yet undetected) circumbinary protoplanet.

Kastner and his students and collaborators are also developing strategies to search for and characterize additional examples of nearby, young, low-mass stars by combining data from NASA’s high-energy archives, such as Galex UV photometry and X-ray data from ROSAT, Chandra, and XMM, with Gaia astrometric and photometric data. In a recent study initiated by CIIS summer (NSF Research Experiences for Undergraduates) research student Matthieu Chalifour, we selected nearly 400 candidate nearby, young, late-type stars in the approximate mass range 0.5–1.0 MJ from the Gaia Data Release 1 (DR1) TGAS catalog on the basis of (a) D < 125 pc, (b) Galex UV detection, and (c) isochronal age ≤80 Myr. Approximately 10% of these candidates lie within 50 pc of Earth and, hence, potentially represent excellent targets for direct-imaging searches for young, self-luminous planets. We have performed a complete spectroscopic and kinematic analysis of this sample, folding in data from Gaia Data Release 2 (DR2), as well as 2MASS/WISE data, ROSAT X-ray data, and optical/IR data from Vizier catalogs. This analysis has established that only a small percentage (<10%) of stars among this (kinematically unbiased) sample can be confidently associated with established nearby, young moving groups (NYMGs). The majority display anomalous kinematics, relative to the known NYMGs. In addition to their non-young-star-like kinematics, the majority of the UV-selected, isochronally young field stars within 50 pc appear surprisingly X-ray faint. These stars may hence represent a previously unrecognized population of young stars that has recently mixed into the older field star population. A paper summarizing these results is under review (Binks, Chalifour, Kastner et al., Monthly Notices of the Royal Astronomical Society, submitted).

Exploring the Molecular Chemistry within Planetary Nebulae

Planetary nebulae form after Sun-like stars go through a phase of extreme mass loss at the end of their life. These objects lose a majority of their
mass (primarily hydrogen and helium, but also carbon, nitrogen, oxygen, and occasionally heavier elements) as the material is pushed outward from the surface of the dying star by radiation pressure and shocks until, eventually, only a hot core remains. As the hotter layers of the stellar core are exposed, they produce high-energy radiation. UV and X-rays from the central star irradiate the expanding shells of ejected gas. The atoms and molecules in the gas re-emit this energy across longer wavelengths like radio and infrared, which we can detect. The planetary nebula has now formed and through this process, Sun-like stars generate crucial atoms (such as C and O) that are ejected into space and might eventually be incorporated into future generations of stars or even planets and potential life on those planets.

Certain planetary nebulae contain shells, filaments, or globules of cold gas and dust whose heating and chemistry are likely driven by UV and X-ray emission from their central stars and from wind-collision-generated shocks. In 2018-19, RIT AST Ph.D. student Jesse Bublitz, supervisor Kastner, and their international team of planetary nebula experts completed analysis of a survey of molecular line emission in the mm wavelength regime range from nine nearby nebulae using the 30-meter radio telescope operated by Europe’s Institut de Radioastronomie Millimétrique (IRAM). Rotational transitions of thirteen molecules, including CO, its isotopologues, and chemically important trace species such as HCN, HNC, CN, and HCO+, were observed and the results compared with and augmented by previous studies of molecular gas in planetary nebulae. Emission lines of the aforementioned molecules were detected in most objects, and one or more of these represent new detections for five of the planetary nebulae studied. Among other results, the Bublitz et al. survey and analysis reveals that the abundance of HCN relative to its molecular isomer HNC within a given planetary nebula is critically dependent on the power of UV radiation from the nebula’s central star. This surprisingly robust correlation between HNC/HCN ratio and central star UV radiation demonstrates the potential of molecular emission line studies of PNe for improving our understanding of the role that high-energy radiation plays in the heating and chemistry of molecular gas in interstellar space. The results of the team’s IRAM 30-meter telescope survey of planetary nebulae has been published as Bublitz, Kastner, et al. (2019, Astronomy & Astrophysics, 625, A101).

Bublitz, Kastner, and team have followed up on their 30-meter telescope survey by scrutinizing the Helix planetary nebula more closely with the IRAM 30-meter. The new observations demonstrate that the Helix -- a particularly nearby, large, molecule-rich planetary nebula that is easily visible in a small telescope at a dark site -- shows a significant decline in its HNC/HCN ratio as one approaches the central star. These results provide “ground truth” for the hypothesis that the relative abundances of HNC and HCN are determined in large part by central star UV radiation.
Cultural Heritage Imaging

Director: Dr. David Messinger

In March 2019, David Messinger, Roger Easton, Tyler Peery and Tania Kleynhans visited the RIT Dubrovnik campus in Croatia. The goal of the visit was to introduce the cultural community in Dubrovnik to multi-spectral imaging for historical document discovery, and foster collaboration with RIT Croatia and the various libraries and archives that hosts magnificent collections of manuscripts.

Through Francis Brassard of the RIT campus in Dubrovnik, we received an invitation to the Public / Scientific Library of Dubrovnik under the leadership of Mrs. Jelena Bogdanovi. She and her staff hosted our public lecture on Monday evening, allowed us to image several items in the collection, and hosted our workshop on Tuesday. Their collection is extensive, and all indications are that a significant portion could benefit from multispectral imaging.

Additionally, we gave a presentation to students at RIT Dubrovnik and Dean Don Hudspeth arranged for us to meet the Mayor of Dubrovnik, Mr. Mato Frankovic, an RIT alumnus. Mr. Frankovic was very supportive of any projects that we can identify to increase the visibility of, and scholarly knowledge about, the extensive collections in Dubrovnik. The city not only has a large collection in the Public / Scientific Library, but also within the three monasteries, the Archive of Dubrovnik, and the Bishop’s Archive. We also met with Mr. Jakov Vetma, the Mayor of Klis and the head of HUPG, the Croatian Association of Historic Towns to talk about the impact of a potential multispectral imaging setup beyond Dubrovnik. They were also sponsoring the “Techne Summit Dubrovnik” on May 3-4 and invited us to present on spectral imaging of historical manuscripts.

The visit was supported through funding by the RIT International Education and Global Programs.

Algorithm development of Hyperspectral data for the automatic characterization of materials in illuminated manuscripts

Research by Tania Kleynhans, advisor: David Messinger. Understanding the materials used in the creation of paintings, illuminated manuscripts and objects can improve conservation techniques and help provide evidence about the origin, techniques used, and authenticity. Significant headway has been made with non-invasive imaging techniques in the past decade. Hyperspectral imaging systems, initially used by the remote sensing community, have
become more widely applied to conservation. Current pigment analysis and mapping of illuminated manuscripts involve significant manual input to create reflectance spectra maps. This research focuses on the development of algorithms that can create material maps from hyperspectral imaging with minimal user input. Algorithms to automatically select the endmembers (i.e. exemplar spectra) and classify the data accordingly have been applied. Figure 1 displays a material map where each color represents a specific known pigment used. This example used the Spectral Angle Mapper algorithm to find similarities between known spectra and the image data. Furthermore, abundance maps have been created from known spectra to display the combination of pigments used in a specific spot. This analysis used hyperspectral imagery acquired by Dr. John Delaney at the National Gallery of Art, Washington, DC. The initial research focuses on one leaf of the Laudario’s of Sant’ Agnese: The Nativity with the Annunciation to the Shepherds, see Figure 2.

Figure 1: The true color Hadrian’s Wall in the Gough Map.

**Pigment mapping of the Gough Map**

Research by Di Bai, advisor: David Messinger. Recently, we developed a novel deep learning approach of HSIIs for pigment mapping of large cultural heritage artifacts, specifically the Gough Map, one of the earliest surviving maps of Britain in geographically recognizable form. Figure 1 displays the true color map. The goal of this work is to develop a deep learning framework, the 3D-SE-ResNet, to classify all the towns, writings and Hadrian’s Wall in the Gough Map with limited amount of labelled data. The results show that with only 5% of the reference data, the neural network achieves high accuracy in object level (identifying towns, writings, etc.).

**Reconstruction of ancient palimpsest text using generative neural networks**

Research by Anna Starynska, advisor: David Messinger. We are developing a method for reconstructing ancient palimpsest manuscripts based on the prior information from other manuscripts that contained script belonging to the same language and calligraphy style as the palimpsested text. In our work we use Generative Neural networks to learn the script alphabet and...
Style from a “clean” manuscript and then use an Inverse neural network to reconstruct the palimpsest characters based on a learned model of the script. This model is the first step of explainable automatic transcription of ancient palimpsest manuscripts using the combination of spectral and spatial information, and a language model.

System Design Considerations for a Low-Intensity Hyperspectral Imager of Sensitive Cultural Heritage Manuscripts

Cultural heritage imaging is becoming more prevalent with the increased affordability of more complex imaging systems, including multi- and hyperspectral imaging (MSI and HSI) systems. A particular concern with these types of systems when imaging sensitive documents is the need for increased signal across a wide spectral range, regularly including infrared and ultraviolet spectra, potentially causing fading or damage to a target. A low-illumination level of 50 lux was chosen for imaging a 14th century Italian palimpsest, based on the United Kingdom standard for cultural heritage display at museums, PAS 198:2012. Ground sample distance (GSD) of the detector system was used as a variable to increase signal-to-noise ratios (SNR) or decrease total illumination time on a target. This adjustment was performed both digitally and physically, and typically comes with a decrease in image quality, as the spatial resolution of the image also decreases. However, a remote sensing technique called panchromatic sharpening was used to recover some of the sacrificed spatial resolution. This method fuses a high spatial resolution panchromatic image with a high spectral resolution MSI or HSI image. Detector systems are investigated that can utilize this technique, as well as additional methods of data capture to assist in processing of sensitive cultural heritage documents, while preserving their physical condition.

Rochester Cultural Heritage Imaging, Visualization and Education Summer Conference 2018

In June 2018, R-CHIVE hosted their second Summer conference. This two day conference was hosted by both the University of Rochester and RIT. The conference was well attended (70 people) from a range of institutions and countries. Topics included historical document material analysis, hyperspectral classification of art, introductions to spectral imaging and the timelines of materials and inks, X-ray fluorescence and diffraction at CHESS, Raman spectroscopy on medieval manuscripts. Short workshops were included for hands-on experience in the form of an image processing workshop, palimpsest making workshop and RTI demonstration.

Ad-hoc activities and conferences

Two presentations were made at the Manuscript Cultures Conference in Hamburg, 14 June 2018: Invited presentation: “Hyperspectral Imaging of Historical Artifacts,” by David Messinger; “Image Quality in Cultural Heritage,” by Tyler R. Peery, Roger L. Easton Jr., Rolando Raqueno, Michael Gartley, David W. Messinger

Presentation by Anna Siebach-Larson, Roger Easton, Steven K. Galbraith, Gregory Heyworth, and Jessica Lacher-Feldman to the “Rare Books and Manuscripts Section” of the Association of College and Research Libraries in New Orleans in June 2018. “Virtual, mechanical, invisible, and radical: Rochester convergences across town and across disciplines.” STEM technologies are dramatically changing the ways that special collections professionals study, preserve, and create access to our collections. These technologies come from disciplines with which special collections have not traditionally collaborated. Professionals in cultural heritage fields may not yet be actively interacting with colleagues in science, technology, engineering, and mathematics, but they will sooner than they think. STEM technologies are not traditionally aligned with cultural heritage fields, yet they are having a profound effect on
our understanding of the historical artifacts in our care.

Imaging of the Codex Zacynthius at Cambridge University Library: Dr. Roger Easton joined a team including Michael Phelps, Damianos Kasotakis, and Keith Knox of the Early Manuscripts Electronic Library in Cambridge UK in July 2018 to image the Codex Zacynthius. The manuscript is a palimpsest and the original (now erased) text of Luke dates from the sixth or seventh century. This text was scraped off in the 13th century and overwritten with the text of an Evangeliarium, composed of passages from the Four Gospels. The book was described by Lord Williams of Oystermouth (Master of Magdalene College and former Archbishop of Canterbury), saying that “We hope that multispectral imaging techniques – such as those used on the Archimedes Palimpsest to reveal mathematical theorems written in the 10th century under Christian texts written in the 13th – will enable scholars to recover fully the hidden text.” Since Dr. Easton had led the Archimedes Palimpsest project in the first decade of the 2000s, he felt very fortunate to work on the Zacynthius as well. The transcription is underway and further image processing can be expected.

Dr. Roger L. Easton, Jr. presented “Multispectral processing methods to recover text from the world map by Martellus (c. 1491)” at the session “From analogue death to digital re-birth” at the Cultural Heritage New Technologies (CHNT) meeting in Vienna, 12 November 2018.

Tania Kleyhans attended the Manusciences ’19 Summer School in Fréjus, France as a student and Dr. Easton as faculty, 11-15 March 2019.

The overall idea of the lecture was to introduce Cultural Heritage Imaging as a growing field of research into the use of novel imaging techniques to study historical objects of known or unknown significance. Of particular interest are imaging techniques that go beyond the capabilities of the human visual system to discover new information about artifacts, either through the enhancement of faded or otherwise unreadable text, or through techniques that study the materials used in the creation and modification of the objects (i.e., pigments, substrates, tools, etc.). The audience could see a high level overview of multispectral imaging and how it is used to “see through” faded, damaged or palimpsested texts. Examples of discoveries made through spectral imaging were also shown and discussed, which was particularly interesting, being that examples included new discoveries within the famous Archimedes Palimpsest at the Walters Art Museum in Baltimore, the World Map by Henricus Martellus Germanus that is located at Yale University and many other. The lecture on the same topic was repeated at the Dubrovnik Public Library the same day and it was open to general public.

On March 19, there was a workshop that took place at the Dubrovnik Scientific Library and the goal of the historical spectral imaging workshop was to familiarize librarians, curators and scholars with the capabilities...
(and shortcomings) of spectral imaging. The workshop was also delivered by Dr Messinger, Dr. Easton and Ms. Kleynhans, and it consisted of short presentations about successful recovery of texts, the basics of spectral imaging, and a high-level overview of how these imaging systems works. Moreover, the RIT team took the opportunity to image a handful of objects from the Scientific library such as parchment fragments, possible palimpsested material and faded text in order to explain and demonstrate the imaging process. This was followed by a discussion and demonstration of how to process the collected images in order to uncover the lost text.

This fascinating series of events was concluded by a round table discussion that took place on March 20 at the Dubrovnik Scientific Library. RIT representatives were joined by local specialists in the field of conservation and Restoration to discuss the outcomes of mentioned lectures and workshops as well as possible future cooperation.

“The entire visit could be seen as a gold-mining expedition. And I believe that we stroke gold! Dubrovnik has a lot of hidden treasures waiting to be discovered. Through a solid support from RIT, such Croatian establishments as the Libraries of Dubrovnik and the State archives in Dubrovnik, could have the means to increase their significance as repositories of cultural and heritage assets with the hope of becoming more attractive for scholars and researchers from all over Europe” concluded Dr. Francis Brassard, professor at RIT Croatia and coordinator of the event.

https://www.croatia.rit.edu/rit-croatia-news/551/3487
Intelligent Vision and Sensing Lab

Director: Dr. Guoyu Lu

Dr. Guoyu Lu organized the 3rd International Workshop on Visual Odometry & Computer Vision Applications Based on Location Clues at CVPR 2019 (Conference on Computer Vision and Pattern Recognition) in Los Angeles.

Dr. Guoyu Lu organized the 3rd International Workshop on Visual Odometry & Computer Vision Applications Based on Location Clues at CVPR 2019 (Conference on Computer Vision and Pattern Recognition) in Los Angeles. The workshop provided a forum for visual odometry and localization, which can be applied to autonomous driving, augmented reality, mobile computing, etc. It attracted around 200 participants from all around the world. The workshop included three keynote speakers (from Australian National University, University of Utah and Google Research, HERE Maps) and four oral paper presentations (authors from Valeo Vision Systems, Nile University, UC Irvine, Harvard University, Google AI, UT Austin, The City College Of New York, Microsoft, University of Pittsburgh).

The lab’s undergraduate student, Sophia Kourian, won the John Wiley Jones Award, which is the most prestigious award for undergraduate students in the College of Science of RIT. She is currently a System Engineer at United Technologies.
The lab’s first PhD student, Yawen Lu, published his first paper in 26th IEEE International Conference on Image Processing during his first year in RIT. The lab received gift funding from Mackinac Technologies to support one year of research on 3D visual surface dimension estimation.

In the coming year the lab will continue the ongoing research in the areas of single image depth estimation, 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:


Guoyu Lu, Yahong Han, “3D Shape Retrieval Through Multilayer RBF Neural Network,” 26th IEEE International Conference on Image Processing (ICIP), 2019
The Machine and Neuromorphic 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. Dr. Kanan also received two significant honors this year. He was elevated to the Senior Membership level of IEEE, and he won the RIT College of Science Distinguished Scholarship Award.

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 DARPA to enable Dr. Kanan’s group to keep pushing the field forward.

With Prof. Nathan Cahill, Dr. Kanan and his PhD student Tyler Hayes created the ExStream method for updating neural networks over time without catastrophic forgetting. The work was published in the International Conference on Robotics and Automation (ICRA-2019), a top robotics conference.

Another major research thrust in the lab is developing systems capable of visually grounded language understanding. These systems process images and videos 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 a paper creating a neural network model for VQA called RAMEN that can answer complicated reasoning questions for synthetic scenes and answer human generated questions about natural scenes. Prior work focused on either of these two problems, but existing systems only worked on a single domain. Those that could reason could not answer human-posed questions about natural scenes, and vice versa. The paper describing RAMEN was published in the IEEE Computer Vision and Pattern Recognition conference (CVPR-2019), one of the most prestigious publication venues in computer vision.

One area where many VQA systems fail is counting objects in scenes. With CIS PhD student Manoj Acharya, Dr. Kanan created the TallyQA dataset for open-ended counting, which has both complex and simple questions. They also created a new algorithm for counting, which surpassed state-of-the-art methods on TallyQA and other datasets. This work was published in the conference AAAI-2019, one of the best publication venues in natural language processing. While there, Dr. Kanan hosted the AAAI-2019 Workshop on the Shortcomings in Vision and Language (SiVL), which he co-organized with researchers from around the world. Over 100 people participated in the workshop.

**Refereed Papers 2018-2019**


Acharya, M., Kafle, K., Kanan, C.


Grants

PI, Using Artificial Intelligence on Street View Imagery to Detect Five Key Invasive Plant Species in New York State. 4/1/2019 – 3/31/22


This is the title of Mandy Nevins’ PhD dissertation which she successfully defended in April. The abstract follows along with a few figures from the dissertation.

Electron microscopes have the capability to examine specimens at much finer detail than a traditional light microscope. Higher electron beam voltages correspond to higher resolution, but some specimens are sensitive to beam damage and charging at high voltages. In the scanning electron microscope (SEM), low voltage imaging is beneficial for viewing biological, electronic, and other beam-sensitive specimens. However, image quality suffers at low voltage from reduced resolution, lower signal-to-noise, and increased visibility of beam-induced contamination. Most solutions for improving low voltage SEM imaging require specialty hardware, which can be costly or system-specific. Point spread function (PSF) deconvolution for image restoration could provide a software solution that is cost-effective and microscope-independent with the ability to produce image quality improvements comparable to specialty hardware systems. Measuring the PSF (i.e., electron probe) of the SEM has been a notoriously difficult task until now. The goals of this work are to characterize the capabilities and limitations of a novel SEM PSF determination method that uses nanoparticle dispersions to obtain a two-dimensional measurement of the PSF (see Fig. 1), and to evaluate the utility of the measured PSF for restoration of low voltage SEM images (see Fig. 2). The presented results are meant to inform prospective and existing users of this technique about its fundamental theory, best operating practices, the expected behavior of output PSFs and image restorations, and factors to be aware of during interpretation of results.

Microscopic Investigation of Gin Trash (GT) in Polypropylene (PP) (Najat Alharbi).

The cotton gin is still being used in harvesting cotton in the US. A large amount of non-cotton material is also harvested and is called “cotton gin trash.” The USDA in New Orleans is interested in finding beneficial uses of this material
and is collaborating with Chemistry, Packaging Science, and the NanolMeaging Lab at RIT to this end. Our role is to study the interface between the GT and the PP matrix using the SEM.

The samples are prepared by freeze-fracturing so as to reveal a native cross section of the PP film with minimal effect of the method used to create the cross section. The film is submerged in liquid nitrogen and once at equilibrium it is removed and flexed so as to fracture. The cross sections are then imaged in the scanning electron microscope. Figure 3 shows a typical result. Because the GT shows a potassium and/or calcium signal in x-ray microanalysis it is easy to discern the GT particles from the surrounding PP matrix.

Polymer TEM Imaging (In collaboration with Professor Carlos Diaz-Acosta of Packaging Science).

There is a large interest in synthesizing biodegradable plastic material for packaging and the Packaging Science department is heavily involved in this endeavor. We are collaborating by providing TEM imaging of cross sections of their materials. These cross sections are created using the ultramicrotome pictured on the Overleaf. Because the materials have low glass transition temperatures the cross sectioning needs to be done at -80 oC. A typical image of a cross section is shown in Fig. 4.

Publications, Conference Presentations, and Patents Issued 2018-2019


**Grants and Contracts 2018-2019**

Cerion Advanced Materials, $28k

**Other Income 2018-2019**

Microscopy Facility User Fees, $78k
Advanced Optical Concepts Laboratory

Director: Dr. Grover Swartzlander

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

This has been another productive year for advanced optical concepts in Dr. Swartzlander’s group. Three students (Lucy Chu, Prateek Srivastava, and Amber Dubill) have contributed to experimental and theoretical development of diffractive solar sails, and another student (Jacob Wirth) has lead an effort to apply computational imaging techniques to the longstanding challenge of protecting camera sensors from damaging laser radiation. The latter work involved a collaboration at the US Naval Research Laboratory (Abbie Watnik). Swartzlander was invited to present two public lectures at the Chicago Museum of Science and Industry, April 13, 2019.

This year Swartzlander won a prestigious and highly competitive Phase II award from the NASA Innovative Advanced Concepts (NIAC) program, teaming with co-investigators from the NASA Marshall Space Flight Center (Les Johnson), the company Beam Engineering For Advanced Measurements or BEAMCo (Nelson Tabiryan), and the University of Alabama (Margaret Kim). Swartzlander also received a new award from the US Office of Naval Research to further develop laser related physics experiments involving sensor protection and laser propagation.

Grover Swartzlander is a Fellow of the Optical Society of America, a NASA NIAC Fellow, a Cottrell Scholar, and an NSF Young Investigator. He recently completed two three-year terms 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 5800 citations for work related to radiation pressure, nonlinear optics, optical vortices, and optical imaging.

Solar and Laser Driven Diffractive Sailcraft for In-Space Propulsion and Navigation

Spacecraft driven only by sunlight (or lasers) provide exciting opportunities to navigate the heavens by converting photon momentum to a mechanical force. This concept was originally proposed almost 100 years ago, using a large area metallic film like the sail of a ship. Swartzlander is pioneering a technique that replaces the reflective sail with a large thin diffraction grating. At RIT his
group was the first team to measure the radiation pressure force on a diffractive layer. This year his group demonstrated that a sail comprised of multiple diffraction gratings can provide advanced functionality. For example, a bi-grating (two gratings that diffract light in opposite directions) was shown to function as a so-called “beam rider”. Beam-riders may be important for both terrestrial and space applications. For example, one of the great challenges of laser propulsion requires a structure that autonomously keeps the light sail in the beam path. The RIT team solved this challenge both theoretically and experimentally. The experimental apparatus is depicted below.

To broadly advance the development of diffractive light sails Swartzlander organized an “OSA Incubator Meeting” in Washington DC at the headquarters of the Optical Society of America. The meeting titled “Metamaterial Films for In-Space Propulsion by Radiation Pressure” was attended by over 30 scientists and engineers from NASA, the Planetary Society, the Breakthrough Starshot Foundation, NIST, NSF, companies, and universities. The incubator meeting was sponsored by the Gordon and Betty Moore Foundation, NSF, NASA, AFOSR, ThorLabs, and Rochester-based Sydor Optics. Topics of discussion included a CubeSat demonstration mission for a light driven sail. CubeSats are small satellites that make use of miniature low mass components, which are perfect for a solar sail. The RIT Space Explorations group (SPEX) has been exploring sail deployment mechanisms for a possible CubeSat mission should funding and launch opportunities transpire.

One of the distinct experiments conducted in the lab was the verification of a beam-rider made of a bi-grating structure, where each grating panel exhibits forces in opposite directions, thereby pulling the bi-grating toward the beam axis while also propelling the structure in the direction of the incident beam. A provisional patent was submitted by RIT for this breakthrough technology.

**Point Spread Function Engineering for Sensor Protection**

Point spread function engineering provides a controlled means of blurring light for a desired purpose, such as the protection of camera sensors from damaging laser radiation. Computational imaging techniques may be used to de-blur the image. A great research challenge is to design a phase mask that both blurs the image and provides high fidelity reconstructed images. Optimum solutions to this problem require a combination of art and science. The image below demonstrates how an engineered point spread function was used to blur the image of a toy tiger (a) and the resulting reconstructed image (b).
Recent Peer-Reviewed Publications


Recent Patents


Grover A. Swartzlander Jr., *Optical Vortex Coronagraph Scatterometer,* non-provisional, RIT ID 2017-007.
Remote Sensing Laboratory

Director: Dr. Carl Salvaggio.

During the 2018–19 academic year DIRS continued its role as a world-class academic research lab focused on the science and engineering of remote sensing systems, technologies, and applications.

New research funding obtained during this past year totaled over $3.7M from fifteen different sponsoring organizations including industry, non-profit organizations, and government agencies. More than ten students (BS, MS, PhD) received their imaging science degrees with a concentration in remote sensing. In addition, our faculty, staff, and students continued to be active professionally by publishing and serving their professions, with their contributions being honored through awards and recognition.

**New research grant highlights of the year included:**

- Professor Charles Bachmann received an award for Remote Multi-Sensor Multi-Angular Terrain Characterization,
- Research Faculty Aaron Gerace received an award from NASA for the Development of Strategies and Instrumentation to Support Landsat Calibration and Higher-level Product Verification,
- Assistant Professor Emmett Ientilucci received an award from ORNL to perform Fundamental Image Science Research,
- Professor Jan van Aardt received an award in Fostering Agricultural Remote Sensing (FARMS) Alliance,
- Professor Jan van Aardt received an award from Love Beets for the Transformation of the New York Table Beet Industry through Digital Agriculture,
- Research Staff member Scott Brown received multiple awards for DIRSIG5 Code and Scene Development Support,
- Research Faculty Michael Gartley, received two awards from Harris Corporation for Image Science and Spectral Modeling and Simulation Support,
• Professor John Kerekes and Research Faculty Michael Gartley received an award from the Department of Energy/LLNL to research Spaceborne Imaging Sensor Modeling and Simulation.

• Professor Tony Vodacek and Associate Professor Matt Hoffman (COS) received an award from the USAF to research High-fidelity scene modeling and vehicle tracking using hyperspectral video, and

• Research Faculty Robert Kremens received multiple awards to research fire combustion processes.

sUAS Remote Sensing Course

Professor Carl Salvaggio, with the assistance of 4th year doctoral student Baabak Mamaghani, is developing and offering a hands-on, systems engineering course made possible by the RIT Signature Interdisciplinary Research Areas - Center for Unmanned Aircraft Systems Research grant. In its second offering, this year-long course has exposed the students to the real-world considerations that must be undertaken in the design of a new, or use of an existing, imaging system to be utilized as part of a small unmanned aircraft system (sUAS). This year the students took an in-depth look at the MicaSense RedEdge sensor used on-board the SIRA/DIRS MX-1 platform. The students performed an end-to-end radiometric characterization/calibration and error analysis as well as a geometric characterization of the 5 individual sensors that compose this multi-camera system.

The radiometric characterization included:
1. Radiometric calibration from normalized digital count to radiance (allowing the camera to be operated in auto-exposure mode; adjusting both its' integration time and gain).
2. Dark noise characterization over the full operational temperature range of the camera (32° to 100°F) at each sensor gain setting.
3. Determination of vignette correction for flat fielding each camera (across all integration times and gains).
4. Determination of the standard errors associated with the integration time, the gain setting, the radiometric calibration coefficients, and normalized digital count.
5. Formation of a partial derivative-based error computation to determine the radiance error that is expected for each pixel in each multispectral band image.
6. Determination of operational lighting levels that this camera could be expected to perform properly (without exhibiting significant degradation in operation).

The students developed their own normalized digital count to radiance methodology and computed the expected errors associated with their method and the calibration method provided by the manufacturer.

The geometric characterization included:
1. The measurement of the system modulation transfer function (MTF) of each camera. MTF was determined using both laboratory and in-field methods.

a. The laboratory approach utilized a knife-edge target in a collimator using the standard slant-edge MTF computations. The students implemented their own versions of the slant-edge method and compared their results to the standard implementation available from Peter Burns.

Figure 1: Undergraduate imaging science student, David Lewis, is making spectral radiance measurements using an Analytical Spectral Devices (ASD) FieldSpec spectroradiometer to determine the uniformity of the radiance field existing the Labsphere integrating sphere in preparation for determining the vignette correction for the MicaSense RedEdge camera.

Figure 2: MicaSense RedEdge green channel collected at 200ft. The scene was collected at the Henrietta Fire Training facility in Rochester, NY and contains several large tarps that were used as slant edge MTF targets for the determination of the system MTF while the sensor was being transported at standard operation flying speeds.
b. The field approach utilized the sensor on-board the SIRA/DIRS MX-1 platform in multiple scenarios; hovering in a stationary position at 100, 200, and 400 feet as well as in a standard flying configuration at normal operational flight speeds. MTF was computed in the along- and across-track directions using large deployed slant edge targets on the ground.

2. The determination of the sensor’s interior orientation and geometric distortion was carried out for each camera in the array. Two approaches were used; the students used the checkerboard approach and the Australis approach. The students were responsible for implementing the checkerboard analysis code for determining the interior orientation and distortion parameters. The distortion corrections from both methodologies were applied to real-world imagery and the efficacy of the results were compared using large in-scene straight edges.

Development of low-cost, field-deployable radiometers for satellite derived land surface temperature algorithm calibration

Drs. Aaron Gerace, Matthew Montanaro, and Robert Kremens along with research staff member Tania Kleyhans and graduate students Jarrett Wehle, Rehman Eon, and Ethan Poole are performing research for NASA Goddard Space Flight Center. The Landsat program is planning to release a Land Surface Temperature (LST) product as part of the Landsat Collection 2 archive. These products, derived from single-channel (Landsats 4 -7) and split window (Landsats 8 and 9) techniques, have been coarsely validated by utilizing large water bodies of known temperatures and by utilizing NOAA’s Surface Radiation Budget network (SURFRAD) broadband radiometers over select land targets. However, these datasets supply limited validation data over a limited range of surface emissivities, temperatures, and atmospheric conditions. A small, low-cost, field-deployable radiometer was constructed using low power electronics and a thermopile built by Dexter Research Center and is being characterized to determine its potential as an accurate instrument for LST validation, see Figure 3. The radiometer contains two spectral channels that mirror the Landsat 8 thermal bands with the flexibility of adding more spectral channels in the future. It is powered by an internal battery, stores the thermal data on a micro SD card, and can be placed in the field to collect data for multiple weeks.

To date, five radiometers have been constructed and used to take thermal measurements of a field on the south end of the RIT campus during two Landsat overpasses, see Figure (right). Comparisons of the measured surface temperatures to the satellite-derived surface temperatures indicate that the radiometers are performing as expected. Two radiometers will be delivered to our collaborators at the University of Arizona and South Dakota State University to test the fidelity of the instrumentation under different environmental conditions. Future radiometer designs will incorporate lessons learned from this first prototype with an emphasis placed on making them field-ready to withstand harsh environmental conditions.

Systems Engineering Support for Next Generation Land Remote Sensing Systems

Dr. Matthew Montanaro and Tania Kleyhans support the radiometric calibration of the Landsat thermal band instruments for the NASA Goddard Space Flight Center. Specifically, this involves the on-orbit characterization and calibration of the Landsat 8 Thermal Infrared Sensor (TIRS) instrument and the pre-flight calibration of the new
TIRS-2 instrument for the upcoming Landsat 9 mission. The PI serves as the Deputy Calibration Lead for the TIRS-2 project and is a member of the Calibration and Validation team for the Landsat program.

The past year has focused mostly on the pre-flight calibration of the TIRS-2 instrument. The main instrument-level characterization tests on the sensor has included electromagnetic interference (EMI) testing and thermal vacuum (TVAC) testing. We supported the EMI and TVAC testing at NASA Goddard Space Flight Center by writing test procedures, coordinating calibration activities with other systems leads, executing calibration data collection procedures, processing and analyzing image characterization datasets, writing requirement verification reports, and presenting results to project management. The main calibration categories include the characterization of the instrument’s radiometric, spectral, and spatial response and the delivery of calibration parameters and algorithms to USGS who will operate the Landsat 9 observatory after launch. Another major effort involved the measurement and optical modeling of the instrument’s stray light characteristics. The TIRS-2 optical design was modified over the TIRS-1 design to mitigate the stray light problem that plagued the TIRS-1 instrument. The PI led the stray light measurements and modeling of the TIRS-2 instrument and reported the results to the TIRS-2 and Landsat 9 project managers. Additionally, we supported the current Landsat 8 product development by helping to characterize and validate new land surface temperature products to be distributed to users. We worked with USGS to develop and implement a split window algorithm for land surface temperature and presented our findings at Landsat calibration and science team meetings.

Using Spectral Imagery to Retrieve Waterbody Component Concentrations

Professor Anthony Vodacek along with research staff member Nina Raqueño and doctoral student Ryan Ford have been focused on using spectral imagery to retrieve concentrations of waterbody components using modeled Look-Up-Tables (LUTs) to determine how imaging systems could be improved for this task, e.g., Landsat. This work extends the LUT retrieval method to assess its ability to retrieve pigments related to harmful cyanobacteria blooms. Imagery from Landsat satellites, as well as multi and hyperspectral unmanned aerial system (UAS) are used for this assessment. The past year we have determined the factors of the LUT retrieval process that affect retrieval error, the largest being atmospheric compensation, sensor noise, and the inputs/design of the LUT, which gives us direction for future work. Some of our improved mapping results are shown in Figure 4 for Owasco Lake. However, the spectral response of a sensor remains critical for water applications and our results demonstrate the value of an imaging spectrometer whether that sensor is on a satellite or a UAS. Our modeling approach was used to test various future Landsat spectral configurations and demonstrated clear improvements when the spectrum is more finely sampled.

Global Surveillance Augmentation Using Commercial Satellite Imaging Systems

Professors John Kerekes and Andreas Savakis, research staff members Jared Van Cor and Dr. Scott Brown along with a team of graduate students from Imaging Science and Computer Engineering including Jobin Mathew, Navya Nagananda, and Bryan Blakeslee have concentrated on developing an automated software system to ingest commercial satellite imagery and automatically detect the presence of certain objects or changes for Kitware and the Air Force Research Laboratory.
Laboratory. RIT has been supporting this project with several tasks.

1. Image Chip Simulation – We have been using DIRSIG to simulate commercial satellite imagery of various objects for use in training deep learning algorithms to perform object detection.

2. Multispectral Change Detection Algorithm Evaluation and Development – We developed a Python toolbox for change detection evaluation and implemented a number of state-of-the-art algorithms for evaluation. Figure 1 presents an example change detection pair and a screen shot of the toolbox interface.

3. Unstructured Change Detection with Class Agnostic Region Proposals – We investigated the use of region proposals to detect unstructured changes in image pairs.

4. Unstructured Change Detection with LambdaNet – We also investigated the use of the LambdaNet neural network architecture to detect unstructured changes in image pairs.

Example graduate dissertations included:

Gregory Patrick Badura: Studies on the Photometric Effect of Roughness

Zhaoyu Cui: System Engineering Analyses for the Study of Future Multispectral Land Imaging Satellite Sensors for Vegetation Monitoring

Sanghui Han: Optimization of Spectral Imaging System Requirements for Subpixel Target

Drones are coming soon to a farm near you

April 23, 2019 by Susan Gawlowicz

Drones are adding a new level of precision to agriculture, giving farmers digital tools for cultivating better and more profitable crops. “The machinery that large farms use—big combines and sprayers—they can take input from GPS and it automates the application process of fertilizer, for example,” said Carl Salvaggio, RIT professor of imaging science. “This technology can also spatially tell you where to harvest to get the best crop product.”

Salvaggio and Professor Jan van Aardt are developing imaging systems at RIT that could make drones commonplace on farms in western and central New York, enhancing the Finger Lakes region’s focus as a food hub, while creating the supporting technology and software companies.

Salvaggio, who leads RIT’s signature research program in unmanned aerial systems (UAS) imaging, offers some ideas on how drones can help farmers. For instance, accurate measurements of soil nutrients and moisture level, disease risk, and plant maturity could take the guess work out of predicting harvesting and processing schedules. Information captured by specialized imaging technology could also reduce the need for chemical controls, by indicating where, when, and how much to apply.

RIT’s remote sensing expertise could also establish technical standards that ensure the scientific integrity of the fledgling industry. Salvaggio, who primarily conducts research for the defense industry, is taking the lead in atmospheric compensation, calibration of imagery, and radiometric processing to ensure continuity in imagery collected over time.

It’s a point of pride for the RIT researcher; if the imagery isn’t
adjusted for atmospheric differences between scenes, dramatic changes in illumination between a sunny morning and an overcast afternoon will skew the data and lead to uninformed decisions at the farm level.

“A lot of people are flying without calibrating their data, and they’re providing data that, to them, looks right,” Salvaggio said. “There is so much promise in these systems, but if you lose the faith of the farmer, you’re never going to get it back, and that could make an industry flourish or totally bankrupt it.”

A regional collaboration of strategic partners, called the FARMS (Fostering Agricultural ReMote Sensing) Alliance, is developing both the unmanned aerial systems technology and the best practices for using it.

Van Aardt is leading this National Science Foundation-funded project focused on remote-sensing applications in snap bean production.

The crop is economically important to New York as one of the biggest producers of processed and fresh market snap beans, following Wisconsin and Florida. The U.S Department of Agriculture, in 2015, ranked snap beans as the fifth largest vegetable crop, in terms of acreage, with a $416 million market value.

The availability of a commercialized imaging product for managing white mold, predicting crop ripeness, and estimating the snap bean yield could have a big impact on farmers. That is welcome news to Jeff Johnson, agricultural manager at the Seneca Foods Corp. location in Geneva, N.Y., who has been talking to van Aardt for years about the need for a better way of managing crops with imaging technology. Johnson is responsible for growing 10,000 acres of snap beans for one of the nation’s largest vegetable processors and relies on crop scouts to monitor the ripening pods and look for signs of white mold.

“When we send people out to the field, they are walking a path,” Johnson said. “We send a drone over the field, it can see the whole field. In theory, we can have a better picture of that whole field than our person does by just walking through it, and labor is becoming more expensive and harder to find.”

The crops are staggered because the processing plant can handle only so many tons per day, and the tight operating schedule isn’t negotiable. “In our world, there’s a 24- to 72-hour window when the beans are ripe,” Johnson said. “It’s critical from our planning standpoint knowing when those fields will be ready to harvest.” The challenge of predicting plant maturity is pushing the limits of remote sensing. Van Aardt is combining hyperspectral imaging to capture light signatures and LiDAR (light detection and ranging) sensors to build a spatial, three-dimensional or topographic picture. “We’re trying to fly a drone, look at a snap bean plant—not even the pods—and see if there is a signal in the plant that tells us the pods are mature or ripe,” he said.

And when it comes to white mold, van Aardt and imaging science MS student Ethan Hughes are identifying the spectral and structural indicators that influence pesticide timing and disease risk. “We want to see—even before the mold occurs—if we can predict where disease incidence will be the highest, so farmers can spray only in those areas,” van Aardt said. “Remote sensing techniques in agriculture hold the promise of standardizing crop assessments with a scientific accuracy not possible from manual observations,” said Sarah Pethybridge, assistant professor of plant pathology at Cornell University.

A white-mold expert, Pethybridge, along with Julie Kikkert at Cornell’s Cooperative Extension, are already developing risk models for snap beans with Salvaggio and van Aardt for an ongoing U.S. Department of Agriculture study. Pethybridge’s project inspired van Aardt to form the FARMS Alliance.

“From the exploratory research done with RIT, we have good spectral signatures to detect flowers, which is an important step in identifying optimal timing of pesticides for white-
mold control,” Pethybridge said. The goal for Salvaggio and van Aardt is to get the information products into the farmers’ hands.

“We use expensive sensors with hundreds of spectral or color channels, but we actually only want to identify five or fewer channels that are useful for specific applications,” van Aardt said. “Then we can transition those five channels into a more affordable sensor that a farmer or a service provider could use operationally.”

Other Agricultural Projects

Drone data collection: RIT is leading the FARMS (Fostering Agricultural ReMote Sensing) Alliance to develop and commercialize drone data collection and analytics for the agricultural industry. The project is supported with a $750,000 National Science Foundation grant and brings together strategic partners in the Finger Lakes region. The core research and technology transfer team includes RIT’s Chester F. Carlson Center for Imaging Science, Saunders College of Business, Venture Creations technology business incubator, Cornell University and Cooperative Extension; the FARMS Advisory Council and Commercial Partners consists of Harris Corp., Agrinetix LLC, Headwall Photonics, Seneca Foods, Love Beets, and Farm Fresh LLC.

Risk models for white mold: RIT researchers are collaborating on two agricultural studies led by Cornell University—one focused on developing risk models for white mold on snap beans for the U.S. Department of Agriculture’s Critical Agriculture Research and Extension Program, and the other to evaluate the table beet production for improved profit and sustainability for Love Beets.

Solving world hunger: Improved safety of unmanned aerial systems (UAS) and drone control software has paved the way for the Federal Aviation Administration to relax restrictions on commercial drone flight. The integration of drones into the national airspace will position the United States to take a stronger role in the global $32.4 billion UAS agriculture market, according to an independent analysis from PrecisionHawk Inc. The technology and data analytics provider collaborates with RIT researchers and has provided the use of its drone platforms.

Agricultural drone imaging has emerged as the dominant focus of RIT’s unmanned aerial systems imaging program, a signature research area. Digital agriculture techniques could help feed the world’s growing population, which the United Nations predicts, by 2050, will reach 9.8 billion and will demand a 70-percent increase in food production from 2006.

Solving global problems with precision agriculture resonates with students in the Chester F. Carlson Center for Imaging Science, said Carl Salvaggio, who leads the signature research initiative. The potential benefits in the agriculture drone industry have sparked interest among students who see a way to make a humanitarian difference.

“We have a lot of students who want to contribute to solving this global food production need,” he said. “It’s exciting that we can attract a new kind of student to imaging science.”


Leaders in drone technology to converge at RIT

Conference on unmanned aerial systems chaired by RIT Assistant Professor Emmett Ientilucci

Worldwide experts in unmanned aerial systems from industry, academia and government will land at Rochester Institute of Technology for the Systems and Technologies for the Remote Sensing Applications Through Unmanned Aerial Systems (STRA TUS) conference Feb. 25-27. The STRATUS conference will explore how drones are revolutionizing fields including precision agriculture, environmental monitoring, and forest and water management, and showcase the latest developments in the hardware and algorithms that power unmanned aerial systems.

Keynote speakers include Sally Rockey, the first executive director of the Foundation for Food and Agriculture Research (FFAR), and Steven J. Thomson, a national program leader at the USDA National Institute Food and Agriculture. The three-day event will also feature tutorials, presentations, posters, sponsors, networking opportunities and vendor demonstrations.

“This conference will promote the dissemination of research results, new ideas and technical advances in
the emerging field of unmanned aerial systems,” said Emmett Ientilucci, assistant professor of imaging science at RIT and the STRATUS program chair. “We hope attendees will gain some general insight to the broad research areas unmanned aerial systems research touches.”

Ientilucci said RIT is an ideal host for the conference because of the Chester F. Carlson Center for Imaging Science and its state-of-the-art Drone Research Lab. He launched STRATUS as a one-day workshop in 2016 with support from the IEEE Geoscience and Remote Sensing Society (GRSS) and it has grown to a three-day event that attracts experts and scholars from as far as Germany, Colombia and Nigeria. This year’s program expanded to include input from nearby universities including University at Buffalo, SUNY College of Environmental Science and Forestry, Cornell University and Hobart and William Smith Colleges.


RIT and Seneca Park Zoo researchers capturing the sights, sounds and insects of Madagascar

Professor Anthony Vodacek helps lay groundwork for new virtual reality experience

Researchers from Rochester Institute of Technology and Seneca Park Zoo are developing a virtual reality gaming environment that will let zoogoers experience a Madagascar rainforest ecosystem. They recently journeyed to the Centre ValBio field station in Ranomafana National Park on a trip that laid the groundwork for creating accurate 3D models of the exotic Madagascar wildlife and habitat.

RIT Professor Anthony Vodacek and Seneca Park Zoo Society Director of Programming and Conservation Action Tom Snyder used remote sensing equipment to examine animals including comet moths, scorpions, katydids and other large insects. The goal is to create the virtual reality gaming environment in the next one to two years.

This will be the second gaming experience RIT and Seneca Park Zoo have created for zoogoers. The zoo is currently beta testing a game that simulates the Genesee River ecosystem. Visitors can play as an otter, a farmer, a homeowner or a scientist to learn about how their actions impact the environment. Snyder said Seneca Park Zoo Society’s partnership with RIT, which was formalized in 2017, has opened his eyes to new approaches to preserving the environment.

“There’s a really cool overlap between technology and conservation,” he said. “You don’t necessarily need to be a conservationist or a biologist to do these types of projects. There’s an interesting and exciting future for remote sensing and many other types of technology in conservation.”

Vodacek worked with Tim Bauch, a senior lab engineer in the Chester F. Carlson Center for Imaging Science, and Morgan Webb, a first-year motion picture science student from Greenwood, Mo., to develop a prototype for a multi-view imaging system to capture the 3D models of the Madagascar wildlife. Vodacek also used a ground-based LIDAR system created by Professor Jan van Aardt to scan the structure of the forest and field microphones to passively record sound for the visualization aspects of the gaming environment. Vodacek is also collaborating with Visiting Assistant Professor Kaitlin Stack Whitney, to analyze the acoustic field recordings and integrate them into her conservation classes. Now that he’s had an opportunity to test the equipment in the field, Vodacek can refine the process and said he sees larger applications for remote sensing insects.

“It would be huge for biodiversity and
the agricultural applications of that are enormous,” said Vodacek. “But it’s a very difficult thing to be able to do, and people don’t talk about remote sensing of insects. I saw this as a preliminary step at expanding the ways we can look and listen for insects. The best process would involve multiple methods all at once—audio, imaging in the visible, infrared, ultraviolet fields.”

Vodacek said his trip, which received funding from the RIT Global Office and College of Science Dean Sophia Maggelakis, opened up the possibility for RIT students to study abroad at Ranomafana National Park in the future. He called Madagascar an ideal spot for research because of the abundance of endemic species that can only be found on the island. While Vodacek prototyped one system to create 3D models of insects, freshmen in RIT’s imaging science program are also creating similar systems for their project-based Innovative Freshmen Experience class. The students will display their findings at the Imagine RIT: Creativity and Innovation Festival on April 27.

During their trip to Madagascar, RIT Professor Anthony Vodacek, second from right, and Seneca Park Zoo Society Director of Programming and Conservation Action Tom Snyder, left, also visited with researchers from the University of Antananarivo.
The Multidisciplinary Vision Research Laboratory (MVRL) seeks to further the understanding of high-level visual perception and support the work of researchers across a number of disciplines, focus areas, and research topics within the Center, College, and University.

Milestones in the MVRL this year included the first journal publication since international patent applications were filed on a new eye-tracking method. Aayush Chaudhary, Ph.D. candidate in the Carlson Center for Imaging Science published the paper (Chaudhary & Pelz, 2019) on the new method for monitoring eye movements based on direct velocity (rather than position) metrics. Chaudhary’s paper describes an extension and application of a method that was originally proposed by Jeff Pelz while on sabbatical in Copenhagen, Denmark, in collaboration with Dan Witzner Hansen of IT University of Copenhagen.

Chaudhary implemented a neural-network approach to segmenting digital video records, allowing the iris region to be reliably isolated in observers with different eye colors and skin tones, a challenge to the original system.

Anjali Jogeshwar defended her MS thesis, Tool for the Analysis of Human Interaction with Two-Dimensional Printed Imagery, based on the work she did on a project funded by the National Academy of Sciences.
Designed to understand complex manual interactions, the experiment required the design of new tools to analyze the interaction between eye gaze and grasp. Jogeshwar trained a network to identify participants’ hands, so that the region of overlap with the underlying surface could be identified as the ‘grasped surface.

Jogeshwar is now continuing her studies in the Imaging Science Ph.D. program, where she is extending her research into the third dimension.

Jeff Pelz published two book chapters this year. The first, “Eyetracking Research,” provides an overview of the area and was published in Cambridge University Press’ Advanced Research Methods for the Social and Behavioral Sciences (Edlund & Nichols, Eds.). The second, “Eye Movement Recordings in Natural Settings,” coauthored with Benjamin Tatler (University of Aberdeen) and Dan Witzner Hansen (IT University of Copenhagen), appeared in Springer’s Eye Movement Research: An Introduction to its Scientific Foundations and Applications (Klein & Ettinger, Eds.). The chapter focuses on a topic central to research in the Multidisciplinary Vision Research Laboratory over the last decade; extending eyetracking into the “real world,” and enabling the analysis of the complex data collected in those settings.

**MVRL Publications: 2018-2019**


