— WELCOME TO THE —

2nd RPI Space Imaging Workshop

October 28–30, 2019

Embassy Suites Saratoga Springs

86 Congress Street,
Saratoga Springs, NY 12866

Hosted and Organized by

Sensing, Estimation, and Automation Laboratory (SEAL)
Department of Mechanical, Aerospace, and Nuclear Engineering
Rensselaer Polytechnic Institute

Find more information online at http://seal.rpi.edu/workshop/2019

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Agenda

Monday, October 28, 2019

7:30–8:30	Registration
8:30–9:00	Welcome
9:00–9:20	**DTM Production from LROC NAC Images** Madeleine R. Manheim (Arizona State Univ.), Megan R. Henriksen (Arizona State Univ.), Mark S. Robinson (Arizona State Univ.), and the LROC Team
9:20–9:40	**Remote Sensing Method to Model Terrain Shape by Detecting Reliable Ground Points** Mohammed A. Yousefhussien, Walter V. Dixon, and James V. Miller (General Electric Global Research)
9:40–10:00	**Planetary Surface Image Generation for Testing Future Space Missions with PANGU** Iain M. Martin (Univ. of Dundee), Martin N. Dunstan (Univ. of Dundee), and Manuel Sanchez Gestido (ESA)
10:00–10:20	Break
10:20–10:40	**Rendering the Titian Environment for Dragonfly** Carolyn A. Sawyer and Nishant L. Mehta (JHU APL)
10:40–11:00	**A Novel Surface Feature Navigation Algorithm Using Ray Tracing** Chris Gnam (Univ. at Buffalo), Andrew Liounis (NASA GSFC), Benjamin Ashman (NASA GSFC), Kenneth Getzandanner (NASA GSFC), Joshua Lyzhoft (NASA GSFC), Jeffrey Small (Aerospace Corp.), Dolan Highsmith (Aerospace Corp.), Coralie Adam (KinetX), Jason Leonard (KinetX), Peter Antreasian (KinetX), and Dante S. Lauretta (Univ. of Arizona)
11:00–11:20	Break
11:20–12:20	**Day 1 Keynote: Carter Emmart (American Museum of Natural History)**
12:20–2:00	Lunch
2:00–2:20	**NASA SPLICE Project: Developing the Next-Generation Hazard Detection System** Carolina I. Restrepo (NASA GSFC), Ronney Lovelace (NASA JSC), Ronald R. Sostaric (NASA JSC), and John M. Carson (NASA JSC)
2:20–2:40	**Monocular Visual-Inertial Odometry with Dynamic LiDAR Scaling for Safe and Precise Landing on Unmapped Planetary Bodies** Chris Owens, Kori Macdonald, Jeremy Hardy, and Andrew Horchler (Astrobotic)
2:40–3:00	**A Vision-Based Navigation Capability for Precise Lunar Landing** Courtney E. Mario, Ted J. Steiner, Laura S. Henderson, Ian T. Fletcher, and Alison M. Siegmann (Draper)
3:00–3:20	**GENEVIS: Generic Vision-Based Navigation for Descent & Landing** Paul Duteis (Airbus Defence), Roland Brochard (Airbus Defence), Darius Djafari-Rouhani (Airbus Defence), and Manuel Sanchez Gestido (ESA)
3:20–3:40	Break
3:40–4:00	**A Comparison of Feature Extraction Methods for Terrain-Relative Navigation** Manoranjan Majji (TAMU), Andrew Simon (TAMU), Carolina I. Restrepo (NASA GSFC), and Ronney Lovelace (NASA JSC)
4:00–4:20	**Efficient Vision-Based Terrain-Relative Navigation Without Dependence on Feature Identification** James S. McCabe (NASA JSC)
4:20–6:00	Break
6:00–9:00	Dinner, Posters, Student Paper Competition

— Evening Posters —

Triangles vs. Quadrilaterals: Selecting the Right 3D Model Format for Space Science and Exploration

Ryan Thibeault, Lillian Hong, and John Christian (RPI)

Deep Learning-Based Crater Detection for Lunar Terrain-Relative Navigation

Lena M. Downes (MIT), Ted J. Steiner (Draper), and Jonathan P. How (MIT)

Analytic Center of Illumination for Groups of Geometric Primitives

Kevin Kobylka and John Christian (RPI)

The Optical Navigation Toolkit

Devin Renshaw, William Parker, Paul McKee, Courtney Hollenberg, Steven Beseler, Chris Grome, and John Christian (RPI)

Visualizing Space Data in Virtual Reality

Lillian Hong, Ryan Thibeault, and John Christian (RPI)

— Student Competition —

Small Body Pose and Shape Estimation from Silhouettes via Extended Target Tracking

Enrico M. Zucchelli, Brandon A. Jones, and Ryan P. Russell (UT-Austin)

Addressing Feature Shadowing with Application to Vision-Based Terrain-Relative Navigation

Jonathan Manni (CU-Boulder), Nisar Ahmed (CU-Boulder), Jay McMahon (CU-Boulder), and Courtney Mario (Draper)

Center and Apparent Diameter Optical Navigation on Mars Orbit

Thibaud Teil (CU-Boulder), Hanspeter Schaub (CU-Boulder), and Daniel Kubitschek (LASP)

Limb-Based Shape Modeling: A Demonstration on Itokawa

Dahlia A. Baker and Jay W. McMahon (CU-Boulder)

Agenda

Tuesday, October 29, 2019

7:30–8:30	Registration
8:30–8:40	Day 2 Opening Remarks
8:40–9:00	**Orion Optical Navigation Performance and Testing** Christopher D'Souza, Rebecca Inman, and Kyle Smith (NASA JSC)
9:00–9:20	**Performance Bounds for Star Centroid Localization in Diffraction-Limited Digital Images** John Christian and Jacob Kowalski (RPI)
9:20–9:40	**Optical Navigation for Autonomous Approach of Small Unknown Bodies** Jacopo Villa (KTH-Royal Inst. of Technology), Saptarshi Bandyopadhyay (JPL), Benjamin Morrell (JPL), Benjamin Hockman (JPL), Shyamkumar Bhaskaran (JPL), and Issa Nesnas (JPL)
9:40–10:00	Break
10:00–10:20	**Optical Navigation for New Horizons Flyby of Kuiper Belt Object (486958) 2014 MU69** Derek S. Nelson (KinetX), Erik J. Lessac-Chenen (KinetX), John Y. Pelgrift (KinetX), Coralie D. Adam (KinetX), Fred J. Pelletier (KinetX), Jeremy Bauman (KinetX), Dale Stanbridge (KinetX), John R. Spencer (SwRI), Simon B. Porter (SwRI), Marc W. Buie (SwRI), Mark E. Holdridge (JHU APL), Harold A. Weaver (JHU APL), Catherine B. Olkin (SwRI), and S. Alan Stern (SwRI)
10:20–10:40	**The Benefits of Subsampling Optical Navigation Images as Applied to the New Horizons Flyby of (486958) 2014 MU69** Declan M. Mages, William M. Owen Jr., Joseph E. Riedel, and Shyam Bhaskaran (JPL)
10:40–11:00	**Optical Navigation Preparations for a Possible Binary System During the New Horizons Extended Mission** John Y. Pelgrift (KinetX), Erik J. Lessac-Chenen (KinetX), Derek S. Nelson (KinetX), Coralie D. Adam (KinetX), Jeremy Bauman (KinetX), Joel Fischetti (KinetX), Fred J. Pelletier (KinetX), Bobby Williams (KinetX), Mark E. Holdridge (JHU APL), Harold A. Weaver (JHU APL), John R. Spencer (SwRI), Simon B. Porter (SwRI), Marc W. Buie (SwRI), Catherine B. Olkin (SwRI), and S. Alan Stern (SwRI)
11:00–11:20	Break
11:20–12:20	**Day 2 Keynote: Andrew Johnson (JPL)**
12:20–2:00	Lunch
2:00–2:20	**Template Matching Used for Small Body Optical Navigation with Poorly Detailed Objects** Joshua R. Lyzhoft (NASA GSFC), Andrew J. Liounis (NASA GSFC), Coralie Adam (KinetX), Peter Antreasia (KinetX), Dante S. Lauretta (Univ. of Arizona), and the OSIRIS-REx Team

2:20–2:40	**Transition from Star-Based to Landmark Optical Navigation During OSIRIS-REx Navigation Campaign at Asteroid Bennu** Coralie D. Adam (KinetX), Leilah K. McCarthy (KinetX), Eric M. Sahr (KinetX), Derek S. Nelson (KinetX), John Y. Pelgrift (KinetX), Erik J. Lessac-Chenen (KinetX), Jason M. Leonard (KinetX), Peter G. Antreasian (KinetX), Eric E. Palmer (PSI), John R. Weirich (PSI), Robert W. Gaskell (PSI), Olivier S. Barnouin (JHU APL), Michael C. Moreau (NASA GSFC), and Dante S. Lauretta (Univ. of Arizona)
2:40–3:00	**Independent Optical Navigation Processing for the OSIRIS-REx Mission Using the Goddard Image Analysis and Navigation Tool** Andrew Liounis (NASA GSFC), Jason Swenson (NASA GSFC), Jeffrey Small (The Aerospace Corp.), Josh Lyzhoft (NASA GSFC), Benjamin Ashman (NASA GSFC), Kenneth Getzandanner (NASA GSFC), Dolan Highsmith (The Aerospace Corp.), Michael Moreau (NASA GSFC), Coralie Adam (KinetX), Peter Antreasian (KinetX), Dante S. Lauretta (Univ. of Arizona), and the OSIRIS-REx Team
3:00–3:20	**The Image Constraint Measurement Type for Orbit Determination and Geophysical Parameter Estimation** Kenneth Getzandanner (NASA GSFC), Jason Leonard (KinetX), Andrew Liounis (NASA GSFC), Erwan Mazarico (NASA GSFC), Coralie Adam (KinetX), Peter Antreasian (KinetX), Dante S. Lauretta (Univ. of Arizona), and the OSIRIS-REx Team
3:20–3:40	Break
3:40–4:00	**Reconstruction of Active Bennu Particle Events from Sparse Optical Data** John Y. Pelgrift (KinetX), Erik J. Lessac-Chenen (KinetX), Coralie D. Adam (KinetX), Derek S. Nelson (KinetX), Leilah K. McCarthy (KinetX), Eric M. Sahr (KinetX), Jason M. Leonard (KinetX), Dante S. Lauretta (Univ. of Arizona), and the OSIRIS-REx Team
4:00–4:20	**Monitoring the Operational Environment of Active Asteroid (101955) Bennu** Carl W. Hergenrother, Frank Shelly, Chester Maleszewski, Rose P. Garcia, Kris Becker, Eric Christensen, and Dante S. Lauretta (Univ. of Arizona)
4:20–4:40	**Towards Robust Learning-Based Pose Estimation of Noncooperative Spacecraft** Tae Ha Park, Sumant Sharma, and Simone D'Amico (Stanford)
4:40–5:00	Break
5:00–6:30	**Seminar: NASA Navigation Filter Best Practices** Russell Carpenter (NASA GSFC) and Christopher D'Souza (NASA JSC)

— Short Course —

Wednesday, October 30, 2019, from 8:30–12:00

Space Image Processing and Computer Vision with MATLAB

Taught by instructors from MathWorks

Keynote Presentations

Monday, October 28, 2019
11:20–12:20

OpenSpace: A Tool for Immersive Interactive Data Context Visualization

Dr. Carter Emmart
Director of Astrovisualization, American Museum of Natural History

OpenSpace is a NASA supported open source software collaboration between the American Museum of Natural History (AMNH) and three leading universities in the fields of data visualization research: Sweden's Linkoping University (LiU), University of Utah's Scientific Computing and Imaging Institute (SCII), and New York University's Tandon School of Engineering. It was designed as an interactive visualization tool to contextualize data and simulations across the known spatial and temporal scale range of the universe presented across a range of display environments. OpenSpace originated from a foundational concept in the millennium rebuilding of New York City's Hayden Planetarium to take audiences beyond the night sky into 3D charted space by visualizing the measured layout of the universe. It has grown from two decades of collaboration with LiU that produced the commercial Uniview software (by SCISS, AB) and precursory tools such as NCSA's Partiview. Influenced by the vast collections at AMNH, its exhibits that contextualize nature across time, and the immersive display tradition of the planetarium, OpenSpace aspires to transport audiences into vast fields of data augmenting what can be seen, traveling to places only visited robotically, and beyond to scales and timeframes impossible to experience in any other way than through rigorous data visualization. Multiple modes of visualization and a modular structure aspire to make OpenSpace a flexible presentation and data exploration tool for a range of users.

Tuesday, October 29, 2019
11:20–12:20

Computer Vision for Planetary Descent and Landing

Dr. Andrew Johnson
Principal Robotics System Engineer, Jet Propulsion Laboratory

The Mars Exploration Rovers used the Descent Image Motion Estimation System (DIMES) to estimate velocity during landing. Although the approach was quite controversial at the time, it was ultimately successful for both Spirit and Opportunity landings. This opened the door for future uses of computer vision during landing, and at that time, the Mars program was particularly interested in position estimation to enable pin-point landing. In 2004, some initial funding was provided to look into its feasibility. Now 15 years later, after numerous starts and stops, changes in funding, distractions and breakthroughs, we have developed the Lander Vision System (LVS) for Mars 2020. This system estimates map relative position during landing so that known hazards in the landing ellipse can be avoided. This talk will start with lessons learned from DIMES and then trace the technology development arc that led to the flight implementation of LVS.

Rensselaer Polytechnic Institute

Rensselaer Polytechnic Institute, founded in 1824, is America's first technological research university. For nearly 200 years, Rensselaer has been defining the scientific and technological advances of our world. Rensselaer faculty and alumni represent 87 members of the National Academy of Engineering, 18 members of the National Academy of Sciences, 27 members of the American Academy of Arts and Sciences, 8 members of the National Academy of Medicine, 8 members of the National Academy of Inventors, and 6 members of the National Inventors Hall of Fame, as well as 6 National Medal of Technology winners, 5 National Medal of Science winners, and a Nobel Prize winner in Physics. With 7,500 students and more than 100,000 living alumni, Rensselaer is addressing the global challenges facing the 21st century — to change lives, to advance society, and to change the world. To learn more, go to www.rpi.edu.

Rensselaer Celebrates Legacy of Space Exploration During Apollo Anniversary

NASA's ongoing exploration of space — celebrated this year with the 50th anniversary of the Apollo 11 mission that landed man on the moon — is inextricably tied to Rensselaer Polytechnic Institute. In a pivotal example, Rensselaer alumnus George M. Low '48 assumed management of the Apollo program after the Apollo 1 disaster and shepherded it through recovery to triumph on July 20, 1969.

Low returned to Rensselaer to become its 14th president, a position he held from 1976 until his death in 1984. Through the decades, the legacy of the connections that took him from Rensselaer to NASA and back has broadened and deepened into generations of contributions by faculty, students, and alumni.

John Christian, the director of the Sensing, Estimation, and Automation Laboratory at Rensselaer, is researching how optical navigation can be used to enable autonomous space navigation. On the Apollo missions, for example, manual navigation with an astronaut-operated space sextant was a back-up for tracking with Earth-based sensors.

Heidi Jo Newberg, a professor of physics, applied physics, and astronomy, studies the structure of the Milky Way, using the location and movement of stars to map the galactic halo and disk. Her work contributes to our understanding of how our galaxy formed and can also be used to determine where dark matter may be located in the galaxy.

Kurt Anderson, a professor of mechanical, aerospace, and nuclear engineering, is designing a compact, semi-autonomous trash collector to address the growing hazards of space debris. It is aptly named OSCaR, which stands for Obsolete Spacecraft Capture and Removal.

The newly established Rensselaer Astrobiology Research and Education (RARE) Center, which is led by Karyn Rogers, an assistant professor of earth and environmental sciences, seeks to discover the conditions that led to the emergence of life on Earth as a means to understand where similar processes may have occurred elsewhere in the universe. Their work is supported, in part, through a $9 million grant from NASA.

The list is extensive. Faculty members are preparing experiments for the International Space Station (ISS), developing technology to cool electronic devices in space, studying the behavior of bacteria in space, and more. Many of these projects involve student participation.

To date, Rensselaer has produced three astronauts: John "Jack" Swigert Jr. '65 was aboard the Apollo 13 mission; Rick Mastracchio '87 became one of the most experienced spacewalkers in history; and G. Reid Wiseman '97 served as flight engineer aboard the ISS for Expedition 41. Additionally, Marta Bohn-Meyer '79 became the first female NASA crewmember assigned to the triple-sonic SR-71 Blackbird aircraft.

The Spirit and Opportunity Rover mission on Mars involved more than a dozen alumni, including Kobie Boykins '96, Michael Meyer '74, and Frederick Serrichio '94, in various aspects of engineering and research. In addition to NASA, Rensselaer students and alumni continue to intern and work at organizations such as SpaceX, Blue Origin, and Lockheed Martin.

— 2019 Workshop General Chair —

John Christian, Rensselaer Polytechnic Institute, chrisj9@rpi.edu

— 2019 Workshop Planning Committee —

Coralie Adam, KinetX
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