1st Annual

RPI Workshop on Image-Based Modeling and Navigation for Space Applications

June 4–5, 2018

Curtis R. Priem Experimental Media and Performing Arts Center (EMPAC)

Rensselaer Polytechnic Institute
Troy, NY 12180

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

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Agenda

Monday, June 4, 2018

KEY

- EMPAC Studio Beta
- EMPAC Main Lobby
- EMPAC Evelyn's Café
- EMPAC Mezzanine
- CBIS Auditorium
- CBIS Meeting Rooms

7:30–8:30	Breakfast & Registration	Evelyn's Café, Main Lobby
8:30–9:00	Welcome	Studio Beta
9:00–9:40	**Fundamentals of Optical Navigation** William Owen (NASA JPL)	Studio Beta
9:40–10:00	**Optical Navigation Preparations for the New Horizons Kuiper-Belt Extended Mission** Derek Nelson, Erik Lessac-Chenen, Coralie Jackman, Fred Pelletier (KinetX)	Studio Beta
10:00–10:20	**Testing of the Orion Optical Navigation Image Processing Algorithm** Rebecca Johanning and Christopher D'Souza (NASA JSC)	Studio Beta
10:20–10:40	**Optical Navigation Algorithm Performance** Cinnamon A. Wright, Andrew J. Liounis, and Kenneth Getzandanner (NASA GSFC)	Studio Beta
10:40–11:00	Break	
11:00–11:20	**Draper's Current Vision Navigation Efforts for Space Applications** Stephen Steffes (Draper)	Studio Beta
11:20–11:40	**Image Processing and Attitude Estimation Performance of Star Camera with Extended Bodies in the Field of View** Malak Samaan (Odyssey Space Research), John Christian (RPI), Steve Lockhart (NASA JSC), and Greg Holt (NASA JSC)	Studio Beta
11:40–12:00	Break	
12:00–12:20	**Tumbling Small Body Spin State Estimation Using Independently Simulated Images** Corwin Olson (UT-Austin), Ryan P. Russell (UT-Austin), and Shyam Bhaskaran (NASA JPL)	Studio Beta
12:20–12:40	**Image Processing for Relative Navigation in Space Rendezvous, Small Body Navigation and Descent and Landing for Planets and Asteroids** Manual Sanchez-Gestido (ESA), Klaus Janschek (Technical University Dresden), Sergey Dyblenko (Technical University Dresden), Sabine Ludwig (Jena-Optronik), Uwe Schmidt (Jena-Optronik), Jesus Gil-Fernandez (ESA), Irene Huertas (ESA), Olivier Dubois-Matra (ESA), Guillermo Ortega (ESA)	Studio Beta
12:40–2:00	Lunch	Mezzanine
2:00–3:00	**Day 1 Keynote: Shyam Bhaskaran (NASA JPL)**	CBIS Auditorium
3:00–3:20	Break	
3:20–3:40	**Autonomous Limb-Based Shape Modeling and Optical Navigation** Jay McMahon and Daniel Scheeres (CU-Boulder)	Studio Beta
3:40–4:00	**Limb-Based Optical Navigation for Irregular Bodies** Andrew Liounis (NASA GSFC)	Studio Beta
4:00–4:20	**Fitting Performance for Horizon-Based Optical Navigation with Cassini Images of Dione and Rhea** Courtney Hollenberg and John Christian (RPI)	Studio Beta
4:20–4:40	Break	
4:40–5:00	**Far-Field Object Characterization in the Presence of Measurement Noise** C. Frueh and S. Fan (Purdue)	Studio Beta
5:00–5:20	**Star Tracker Attitude Solution from Spinning Platform with Rapid Streak Detection** N. Houtz and C. Frueh (Purdue)	Studio Beta
5:30–6:00	EMPAC Tour (optional)	
6:00–9:00	Dinner, Posters, Student Paper Competition	Main Lobby

Posters

Rendering an Image from Stars to Asteroids

N.L. Mehta, P.S. Ericksen, and C. A. Sawyer (JHU APL)

A Tool for Evaluating Surface Coverage

Andrew J. Liounis (NASA GSFC), Kenneth Getzandanner (NASA GSFC), John Weirich (PSI), Eric Palmer (PSI), and Olivier Barnouin (JHU APL)

Astrobotic Research and Development: Vision-Based Navigation Solutions for Spacecraft

Kerry Snyder, Eric Amoroso, Fraser Kitchell, and Andrew Horchler (Astrobotic Technology, Inc.)

Software Architecture for Closed-loop Autonomous Optical Navigation Scenarios

Thibaud Teil and Hanspeter Schaub (CU-Boulder)

Selection of Opportunistic Landmarks for Vision-Based Terrain Relative Navigation Above a Planetary Surface

Kevin Kobylka and John Christian (RPI)

Camera Calibration and State Estimation for the Cislunar Explorers Optical Navigation Subsystem

Michael Wang, Anshuman Das, Kyle Doyle, and Mason Peck (Cornell)

Agenda

Tuesday, June 5, 2018

KEY

- EMPAC Studio Beta
- EMPAC Main Lobby
- EMPAC Evelyn's Café
- EMPAC Mezzanine
- CBIS Auditorium
- CBIS Meeting Rooms

7:30–8:30	Breakfast & Registration	
8:30–8:50	**SPC at 30** Robert Gaskell (PSI)	
8:50–9:10	**The Small Body Mapping Tool (SBMT) for Accessing, Visualizing, and Analyzing Spacecraft Data in Three Dimensions** O. S. Barnouin, C. M. Ernst, R. T. Daly, M.I. Zimmerman, J.M. Peachy, and the Small Body Mapping Tool Team (JHU APL)	
9:10–9:30	**Theoretical and Empirical Performance Evaluation of Stereophotoclinometry in Support of OSIRIS-REx** E. E. Palmer (PSI), J. R. Weirich (PSI), R. W. Gaskell (PSI), O. S. Barnouin (JHU APL), M. Daly (York Univ.), and D. S. Lauretta (Univ. of Arizona)	
9:30–9:50	Break	
9:50–10:10	**In-Flight Calibration of the OSIRIS-REx Optical Navigation Imagers** John Pelgrift (KinetX), Eric Sahr (KinetX), Derek Nelson (KinetX), Coralie Jackman (KinetX), Lylia Benhacine (Draper), and Brent J. Bos (NASA GSFC)	
10:10–10:30	**Optical Navigation Simulation and Performance Analysis for OSIRIS-REx Proximity Operations** Coralie Jackman (KinetX), Leilah McCarthy (KinetX), Eric Sahr (KinetX), Derek Nelson (KinetX), Jason Leonard (KinetX), Peter Antreasian (KinetX), Eric Palmer (PSI), John Weirich (PSI), and Andrew Liounis (NASA GSFC)	
10:30–10:50	**Image Correlation in Unknown Environments for OSIRIS-REx Asteroid Sample Collection** Courtney Mario (Draper)	
10:50–11:10	Break	
11:10–11:30	**Mapping Bennu with Sunlight and Lasers: The SPCOLA methods** J. H. Roberts (JHU APL), O. S. Barnouin (JHU APL), R. W. Gaskell (PSI), E. E. Palmer (PSI), J. R. Weirich (PSI), M. Daly (York Univ.), J. Seabrook (York Univ.), R. C. Espiritu (JHU APL), A. H. Nair (JHU APL), M. E. Perry (JHU APL), and D. S. Lauretta (Univ. of Arizona)	
11:30–11:50	**Vision Navigation using the ISS Selfie video data** Fredy Monterroza (Draper)	
11:50–1:00	Lunch	
1:00–2:00	**Breakout Sessions**	
2:00–3:00	**Day 2 Keynote: Jan-Michael Frahm (UNC at Chapel Hill)**	
3:00–3:30	Break	
3:30–3:50	**Assessment of Vision-Based Terrain Relative Navigation Algorithms** Lylia Benhacine (Draper)	
3:50–4:10	**RVS3000-3D: LIDAR meets Neural Networks** Christoph Schmitt, Johannes Both, and Florian Kolb (Jena-Optronik)	
4:10–4:30	**Optical High-Dynamic-Range Spacecraft Relative Navigation: Advances in Algorithms and Hardware-in-the-Loop Validation** Joshua Sullivan, Sumant Sharma, Connor Beierle, and Simone D'Amico (Stanford)	
4:30–4:40	Closing Remarks	

Breakout Sessions

There will be three parallel breakout sessions from 1:00–2:00 on June 5. Each session will begin with a brief introduction by the moderator to frame the topic, followed by an open dialogue amongst session participants. Everyone is encouraged to actively participate in the conversation! These informal sessions are an opportunity for workshop attendees to explore challenges of interest to the community, share new developments of note, and identify important areas of future work. We hope that the discussions will enable the exchange of new ideas and be a catalyst for new collaborations.

Breakout Session #1

Cis-Lunar Optical Navigation (OPNAV)

Moderator: Scott Cryan, NASA Johnson Space Center

With plans for cis-lunar spacecraft (manned and un-manned) to become less reliant on Earth assets, desire/need exists to perform GNC autonomously. Ability to use passive sensors, such as visible and infrared cameras, to support navigation determination is highly desirable. Performing absolute navigation as well as relative navigation (monitoring of incoming visiting vehicles) with target vehicle based cameras and avionics provides a viable means of navigation methods that do not rely on active/transmitting sensors. Can Optical Navigation (OPNAV) provide desired accuracies to support absolute navigation and relative navigation?

Breakout Session #2

Information Overload: Challenges for Data Management in Small Body Modeling

Moderator: James Roberts, Johns Hopkins University Applied Physics Laboratory

Over the past 20 years, tremendous advances have been made in the collection, analysis, and visualization of spacecraft data used to model the topography of small planetary bodies. Shape models of a dozen near-earth and main-belt asteroids, a few comets, and several small moons are widely available, from ground-based radar and in-flight LIDAR; as well as from visible images using both stereophotogrammetry and stereophotoclinometry.

This session will explore a new set of challenges we face: dealing with all this data! Our data management approach must be able to handle both data-rich and data-poor scenarios. Orbital campaigns often produce a wealth of data from a variety of sensors that must be combined, interpreted, and visualized to produce meaningful science products. Conversely, flybys of small bodies on the way to another target often provide only limited observations during the brief encounter. This leads to a strong need for making the most of one flyby's worth of data so that we can get the best shape models possible of these fleeting targets. In both cases (orbit and flyby), there is a need to manage data from disparate sensors in the most efficient, insightful, and transparent way possible. This is the focus of our breakout session.

Breakout Session #3

Identifying the Next Generation of Computer Vision Problems for Space Applications

Moderator: John Christian, Rensselaer Polytechnic Institute

Space-based imagery is often expensive to obtain and limited in geometric diversity. This has led the broader space community to develop sophisticated methods for extracting the maximum amount of information from limited collections of images. Meanwhile, the field of computer vision has matured considerably, and what was first thought doable as a simple summer project at MIT in 1966 has blossomed into one of the most fruitful fields of research of the last half-century. Despite these parallel histories, the space exploration and computer vision communities have not interacted as much as would be hoped. As a result, we find that many classic computer vision algorithms cannot be effectively applied to space imagery due to implicit (and sometimes very subtle) assumptions about operating in a terrestrial environment.

In this breakout session participants are encouraged to share the challenges they've encountered while implementing standard computer vision methods in the space domain. Our objective is to better understand the current shortcomings and to identify a fundamental set of computer vision problems that need to be solved. This may be used to better engage the computer science community with challenging problem sets of direct relevance to space science and space exploration.

Keynote Presentations

Monday, June 4, 2018
2:00–3:00, CBIS Auditorium

Image-Based Deep Space Navigation: Finding our Way Around the Solar System One Picture at a Time

Dr. Shyam Bhaskaran
Supervisor, Outer Planets Navigation Group
Jet Propulsion Laboratory/California Institute of Technology

Since the dawn of the Space Age, spacecraft have carried cameras to take pictures of Solar System bodies they encountered, including planets, planetary satellites, asteroids, or comets. These images obviously have tremendous scientific value, as much of the knowledge we have gained about these bodies came from the pictures. They are also of great value for public relations and outreach; images of our neighbors in the Solar System spark the imagination and provide inspiration for generations of scientists and engineers to pursue a career in space science, and for the public at large to share in the excitement of space exploration. For space navigators, the images are also a powerful tool for precisely navigating a spacecraft to its intended target. This discipline, called Optical Navigation (OPNAV), has enabled remarkable accuracies; examples include the Cassini spacecraft's ability to target flybys of Titan (Saturn's largest moon) to less than 1 km, and the Deep Impact spacecraft's collision with comet Tempel 1 at a speed of over 36,000 km/h. This talk will provide a brief background of deep space navigation, the fundamentals of OPNAV technique, and examples of its current usage. It will also touch on a history of OPNAV, how it has enabled autonomous spacecraft navigation, and its future potential.

Tuesday, June 5, 2018
2:00–3:00, CBIS Auditorium

Large-scale Robust Estimation of 3D World Models Leveraging Crowd-Sourced Data

Dr. Jan-Michael Frahm
Professor, Department of Computer Science; Director, 3D Computer Vision Group
University of North Carolina at Chapel Hill

Crowd-sourced imagery (images and video) is the richest data source available for 3D reconstruction of the world. The tremendous amounts of available imagery provided by photo/video sharing websites, not only covers the world's appearance, but also reflects the temporal evolution of the world, and its dynamic parts. It has long been a goal of computer vision to obtain lifelike virtual models from such rich imagery. The major current research challenges are the scale of the data, e.g. the Yahoo 100 million-image dataset (only presents a small fraction of what is needed to model our world), the robustness, the completeness of the registration, and the lack of data for dynamic elements. Specifically, we are currently facing significant challenges to process Internet scale crowd-sourced imagery within a reasonable time frame given limited computer resources. This is particularly true as we move toward automatically creating content for personal virtual and augmented reality. The talk discusses our work on highly efficient image registration for the reconstruction of static 3D models from world-scale photo collections on a single PC in the span of six days, as well as our related work on image-based search to address the scalability. It will also discuss the efforts to overcome the challenges of achieving registration completeness and robustness. Our novel streaming reconstruction approach aims to ease the above current challenges to estimate a 3D world model from unorganized image data. Additionally, our work towards overcoming the lack of observations for the reconstruction of scene dynamics will be presented. This includes, for example, reconstructing people and fountains, using crowd-sourced imagery and videos to achieve the goal of bringing the 3D models to life.

Stereophotoclinometry (SPC) Short Course, June 6–8, 2018

Instructors: Robert Gaskell and Eric Palmer, Planetary Science Institute (http://www.psi.edu)

SPC is a technique for building digital terrain models that combines the accuracy of stereophotogrammetry with the high-resolution capabilities of photoclinometry. It has been used on missions such as Dawn, Rosetta, Cassini, Hayabusa, and NEAR. This hands-on class will provide training on both the theoretical background of SPC and provide pragmatic training on how to run the software. A separate registration is required to attend this short course.

Rensselaer Polytechnic Institute

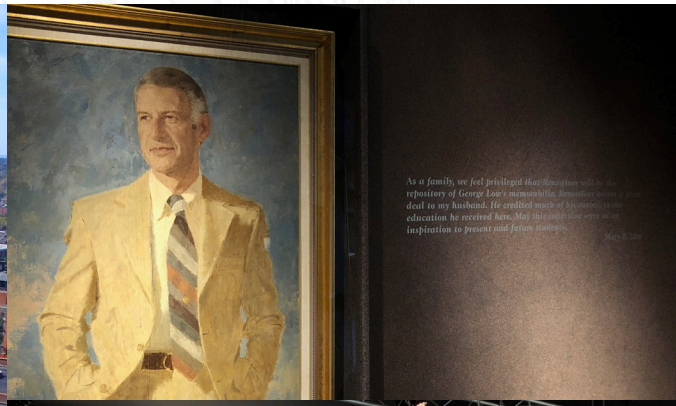
Rensselaer Polytechnic Institute, founded in 1824, is America's first technological research university. For nearly 200 years, Rensselaer has been defining the scientific and technological advances of our world. Rensselaer faculty and alumni represent 86 members of the National Academy of Engineering, 17 members of the National Academy of Sciences, 25 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 5 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 7,000 students and nearly 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.

George M. Low Gallery

If you have extra time during your visit to Rensselaer, we encourage you to visit the George M. Low Gallery. The Low Gallery is located on the fourth floor of the Low Center for Industrial Innovation (building 14 on your RPI Campus Map).

George M. Low received his B.S. ('48) and M.S. ('50) in aeronautical engineering from Rensselaer Polytechnic Institute (RPI). Following graduation, Low joined NACA as an aeronautical engineer. After the formation of NASA in 1958, Low was named Chief of Manned Space Flight, where he played an instrumental role in the Mercury, Gemini, and Apollo Projects. Following the Apollo 1 fire in 1967, Low was named Manager of the Apollo Spacecraft Program Office (ASPO). He is widely credited with his central role in helping NASA recover from the Apollo 1 disaster and the ultimate success of the Apollo Program. Low became NASA Deputy Administrator in 1969, a role he held until his retirement from NASA in 1976. After departing NASA, Low was named the 14th President of RPI. He held this position until his death in 1984.

The George M. Low Gallery at RPI contains historic NASA memorabilia, Low's Presidential Medal of Freedom (the highest civilian award in the United States), and various items of personal and professional significance. The gallery is maintained by the RPI Delta Phi fraternity, of which Low was a proud member.



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A special thanks to all of the RPI and EMPAC staff who helped make this workshop possible, especially Sue Miller, Rose Boshoff, Lauren Marchese, Pamela Smith, Heather Carroll, John Cook, and Michele Cassaro. We also appreciate the help of Jenn Carr from RPI and Arlen Johnson from Spherical Cow Group for the help with the workshop website. This workshop would not have been possible without their dedicated support and help.

Save the Date for next year!

2nd Annual RPI Space Imaging Workshop

October 2019