The University of Texas at Austin
Cockrell School of Engineering

Cockrell School of Engineering

Crater-Based Navigation and Timing for Small Satellites in Low-Lunar Orbit

Interplanetary Small Satellite Conference

Brandon A. Jones, Renato Zanetti,
Sofia Catalan, Rachael Gold, Z McLaughlin

May 2-3, 2022

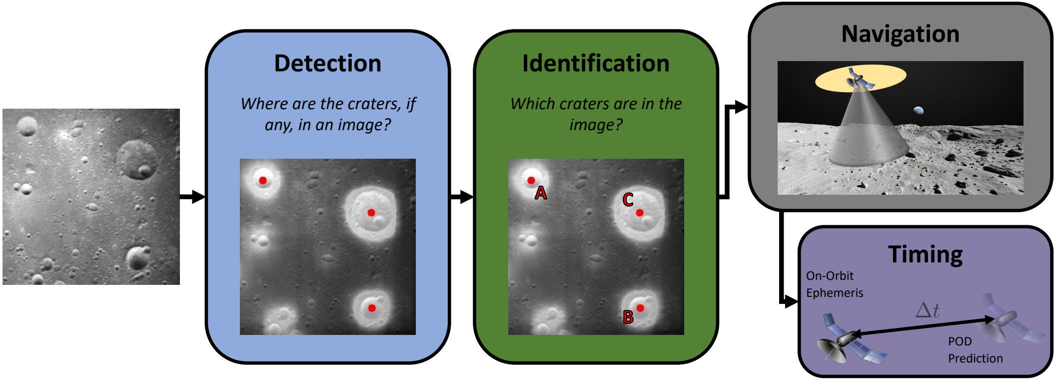
This work is funded under NASA Cooperative Agreement (CA) 80NSSC20M0087 as part of the
Small-satellite Technology Partnership (STP) Program

Current State-of-the-Art

- Overtaxed ground-base systems - Deep Space Network
- SWaP incompatible with small satellite - pulsar-based navigation
- Requires communication with additional spacecraft - satellite cross-link communication (e.g., LiAISON)
- Optical tracking of spacecraft/bodies with known ephemerides - JPL's AutoNav, Orion optical navigation for Artemis

Optical navigation of craters provides a software-based solution to PNT with the use of a camera (low SWaP).

Overview of CNT System



Brief History of Lunar Crater-based Navigation

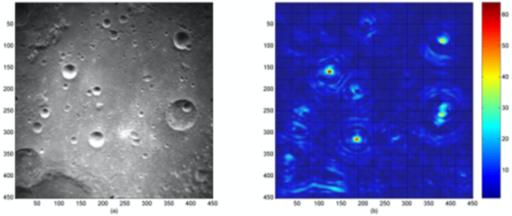
- Initial studies in support of Constellation Program

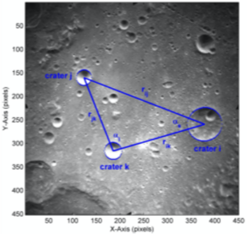
  Jones (2008); Hanak (2009); Singh and Lim (2008); Osenar et al. (2008); Getchius et al. (2008)

- Ongoing studies on Terrain Relative Navigation (TRN) for landing Downes et al. (2021); McCabe and DeMars (2019); Shoemaker et al. (2022)

- Orion optical tracking of moon for navigation in cislunar space

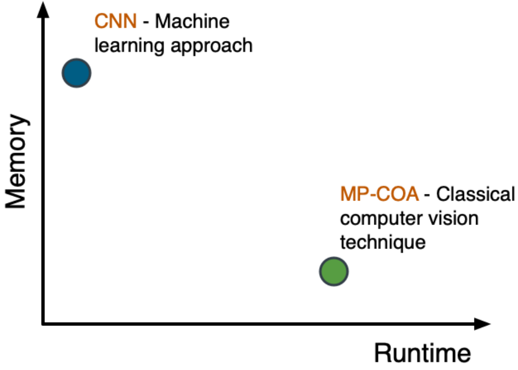
  Christian and Lightsey (2009); Christian (2009); Holt et al. (2018)





Images: Hanak (2009)

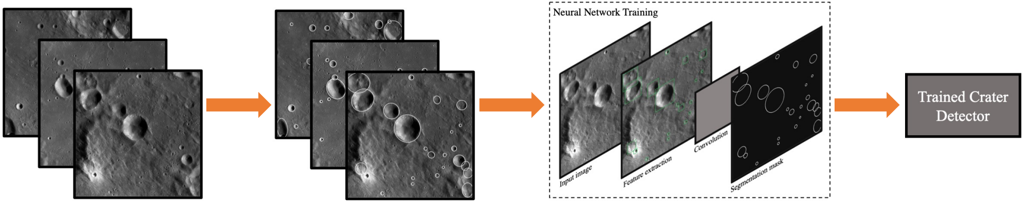
Image Processing Trades



- Navigation update rate: 5 sec.
- Unoptimized CNN will execute on Jetson TX2/Xavier in required time
- Ongoing work to optimize neural network for less-capable processor
- Leveraging experience with neural network optimization for JSC Seeker-1 mission

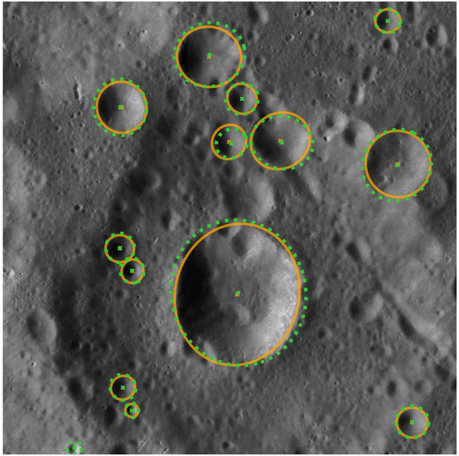
Detector Training Pipeline

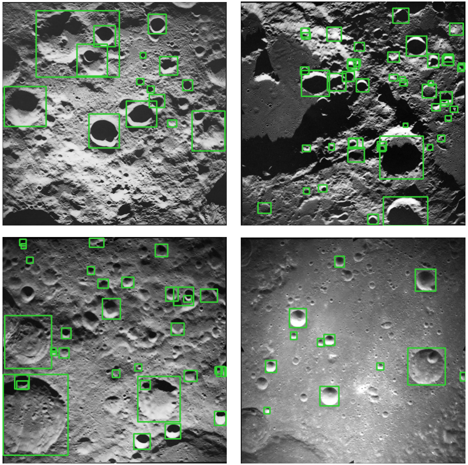
- Image processing through Mask R-CNN and OpenCV enables the detection of multiple craters in the camera field of view
- With an automated and iterative pipeline, a trained detector model is built using image samples from the LROC Global Morphologic Maps



Input Images | Automated Labeling | Mask R-CNN Training | Detector Model

Detector Performance Illustration

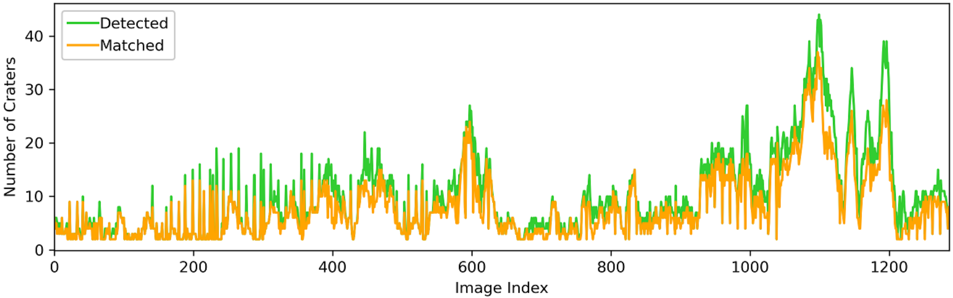




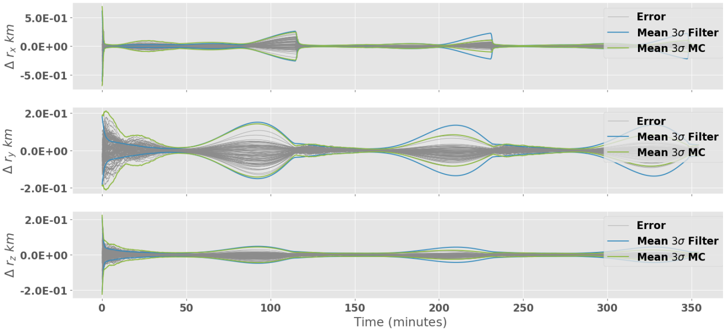
Crater Catalog and Identification

Robbins lunar crater database

- ∼1.3 million craters
- Incorporates measurements from NASA LRO and JAXA SELENE missions



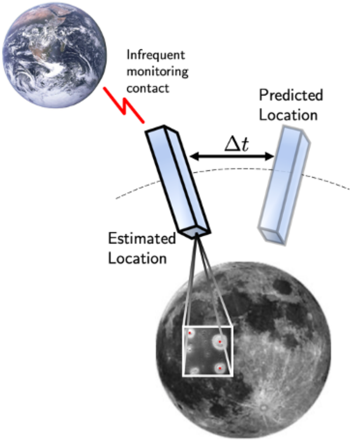
Filter Position Estimation



Cases	x (km)	y (km)	z (km)	3D (km)
Dark Side 0	0.044	0.041	0.009	0.061
Dark Side 1	0.032	0.045	0.040	0.069
Dark Side 2	0.078	0.076	0.050	0.120
Dark Side 3	0.079	0.078	0.024	0.114

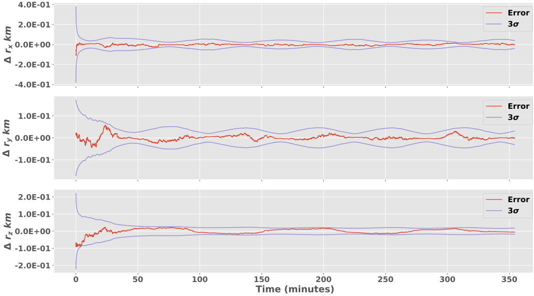
Time Bias Estimation

- Assumption: Asset will have some, possibly infrequent, contact with the ground.
- Ground-based tracking and POD solution may be used to generate a predicted ephemeris
- On-board clock bias/drift may be asynchronously estimated as predicted ephemeris is available

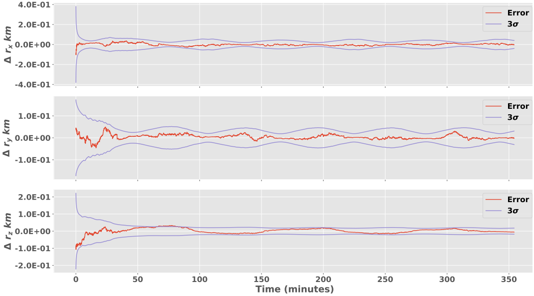


Time Bias Performance

2 second bias, ephemeris at start



20 second bias, ephemeris at start



- Asynchronous operation of time bias estimation
- Current efforts are looking to remove the need for uploaded ephemeris

CNT System Dependencies

1. Camera with sufficient resolution
   - Capable of resolving craters at desired orbit altitude(s)
2. Intermittent communication with ground/operator
   - Only required for time-bias estimation
   - Current efforts underway to remove this need
3. Core Flight System (cFS)-based runtime environment (optional)
   - Software written in C/C++
   - Can be ported to other real-time environments
4. CPU bandwidth for image processing

Moving Forward

- Continue testing of integrated solution to increase TRL
- SCOPE mission in development to demonstrate key components in LEO
  - Algorithms and computation needs/requirements
- New method in development to remove need for ground-based tracking for time bias estimation
- Enhance detector performance (precision, recall, and centroid accuracy)

THANK YOU

Brandon A. Jones, Assistant Professor
brandon.jones@utexas.edu
https://sites.utexas.edu/bajones

- Catalan, S., J.M. McCabe, and B.A. Jones, "Implementation of Machine Learning Methods for Crater-based Navigation", *2021 AIAA/AAS Astrodynamics Specialist Conference*, August 9-11, 2021.
- McLaughlin, Z.R., R.E. Gold, S.G. Catalan, B.A. Jones, and R. Zanetti, "Crater Navigation and Timing for Autonomous Lunar Orbital Operations in Small Satellites", *44th Annual AAS Guidance, Navigation, and Control (GN&C) Conference*, Feb. 4-9, 2022.