



Cockrell School of Engineering

Crater-Based Navigation and Timing (CNT)

2022 STP Technology Exposition - June 8, 2022

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Cooperative Agreement (CA): 80NSSC20M0087
NASA Support: Johnson Space Center



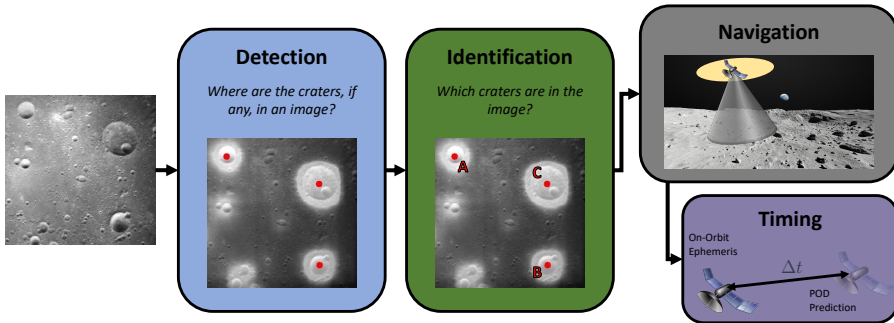
Current State-of-the-Art

- ▶ Overtaxed ground-base systems - Deep Space Network
- ▶ SWaP incompatible with small satellite - pulsar navigation, deep space atomic clock
- ▶ Requires specialized equipment or additional spacecraft - Cislunar Autonomous Positioning System
- ▶ Optical tracking of spacecraft 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



- ▶ Starting point: Work done by JSC and others in early- to mid-2000s for Constellation Program
- ▶ Timing solution is a new approach not considered previously

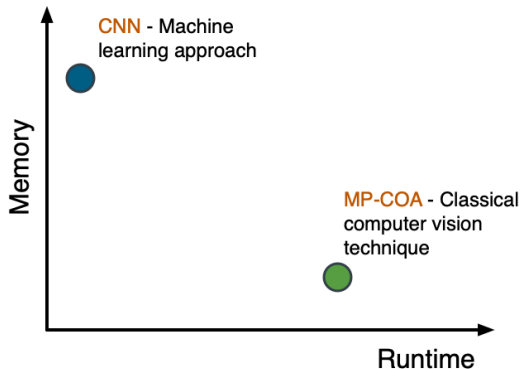


CNT System Dependencies

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



Image Processing Trades

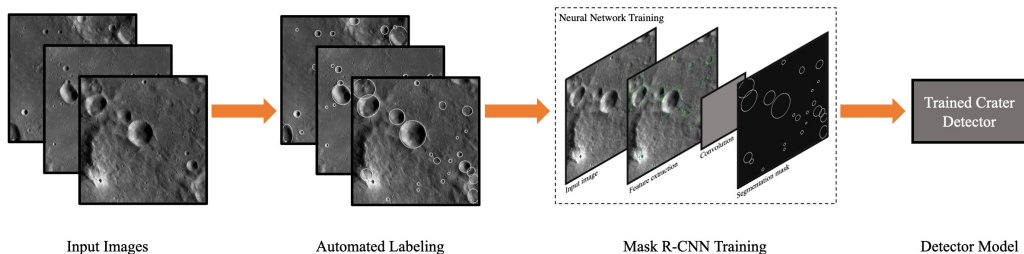


- ▶ Navigation update rate: 5 sec.
- ▶ Unoptimized CNN will execute on Jetson TX2/Xavier in required time
- ▶ Ongoing work to optimize neural network for less-capable processor
- ▶ Leveraging experience with neural network optimization for JSC Seeker-1 mission



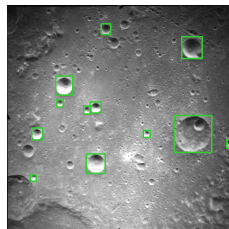
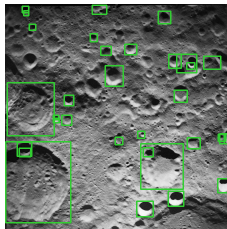
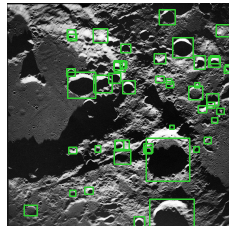
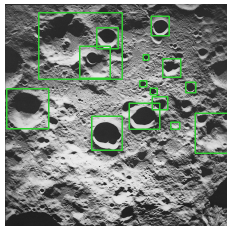
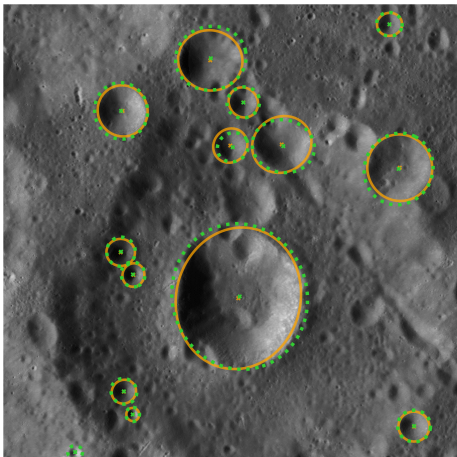
Detector Training Pipeline

- ▶ 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





Detector Performance Illustration

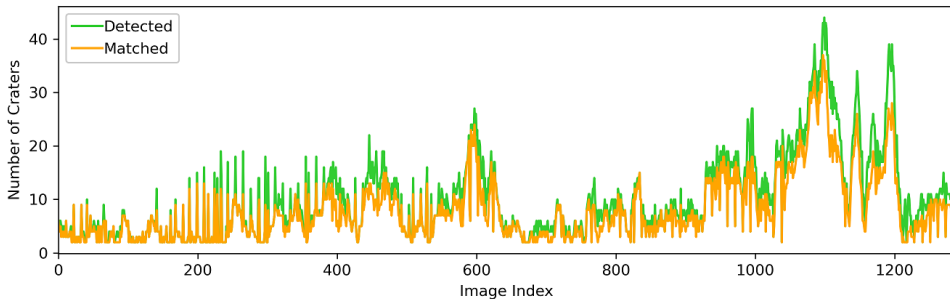




Crater Catalog and Identification

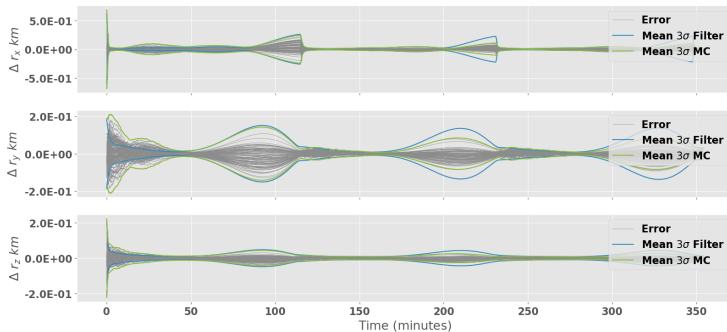
Robbins lunar crater database

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





Filter Position Estimation

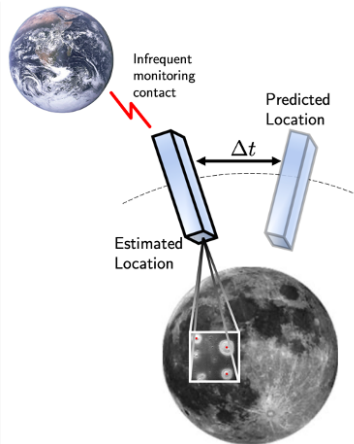


Cases	x (km)	y (km)	z (km)	3D (km)
Dark Side 0	0.044	0.041	0.009	0.061
Dark Side 1	0.032	0.045	0.040	0.069
Dark Side 2	0.078	0.076	0.050	0.120
Dark Side 3	0.079	0.078	0.024	0.114



Time Bias Estimation

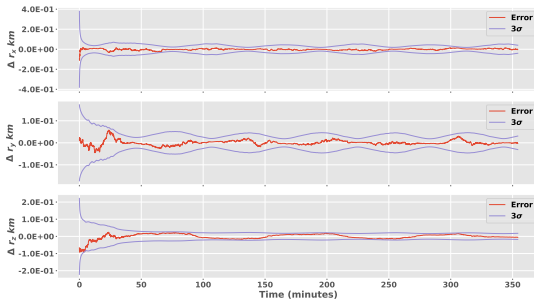
- ▶ **Assumption:** Asset will have some, possibly infrequent, contact with the ground.
- ▶ Ground-based tracking and POD solution may be used to generate a predicted ephemeris
- ▶ On-board clock bias/drift may be asynchronously estimated as predicted ephemeris is available



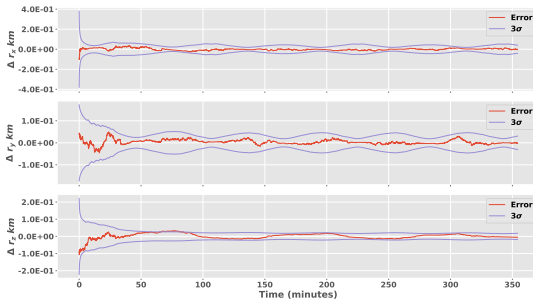


Time Bias Performance

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



Potential Applications/Uses

PNT for the following cases/regimes:

- ▶ Mid- or low-lunar orbit for terrain-relative navigation
- ▶ Initial lunar landing phases (where craters still contained in a single image)
- ▶ Possible use at Mercury or other crater-covered bodies
 - Requires a catalog of known craters



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

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