Cockrell School of Engineering

# Crater-Based Navigation and Timing (CNT)

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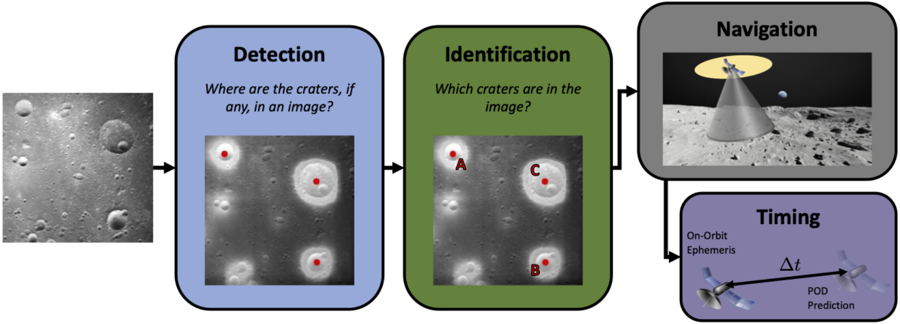
NASA Support: Johnson Space Center

# 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

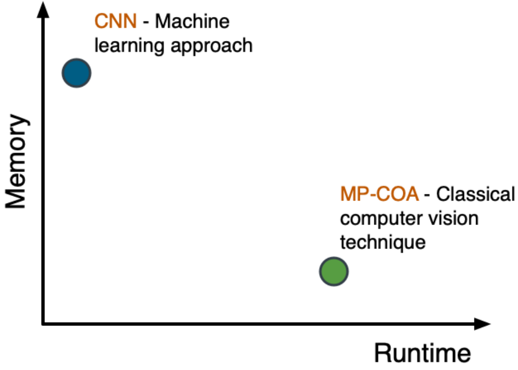



- Starting point: Work done by JSC and others in early- to mid-2000s for Constellation Program
- Timing solution is a new approach not considered previously

# 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

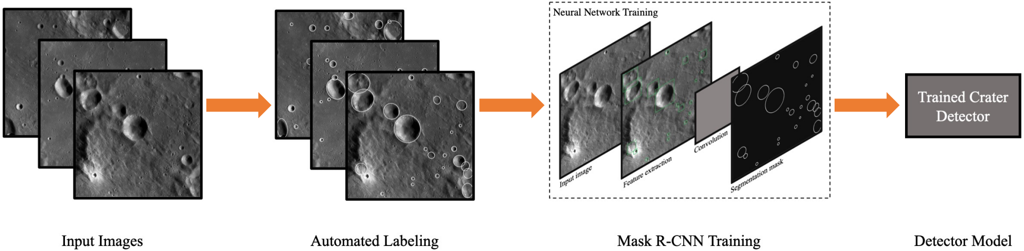
# Image Processing Trades



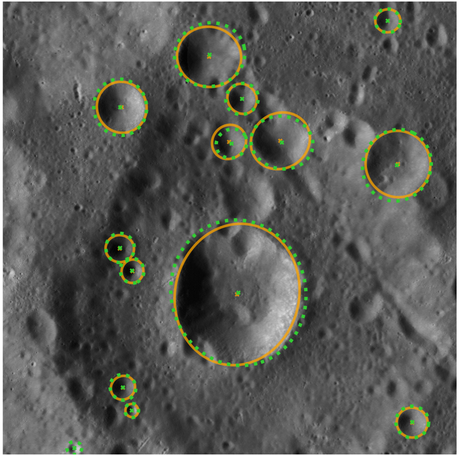

- Navigation update rate: 5 sec.
- Unoptimized CNN will execute on Jetson TX2/Xavier in required time
- Ongoing work to optimize neural network for less-capable processor
- Leveraging experience with neural network optimization for JSC Seeker-1 mission

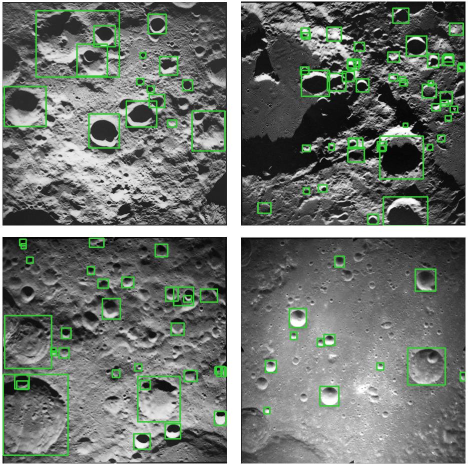
# Detector Training Pipeline

- 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

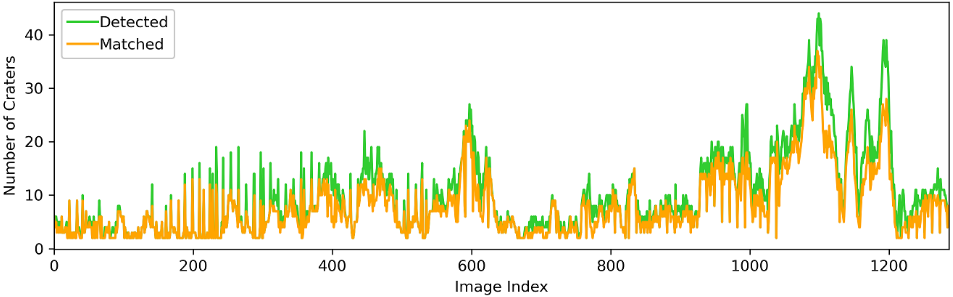




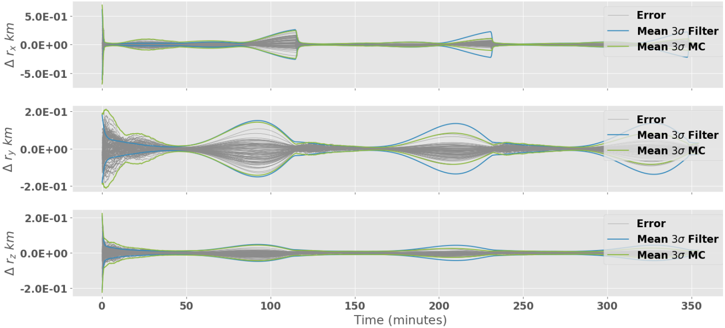
# Crater Catalog and Identification

## Robbins lunar crater database

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



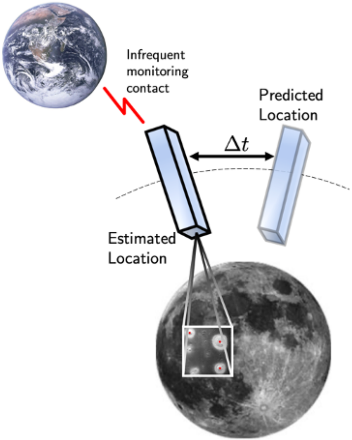
# Filter Position Estimation




| 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 |

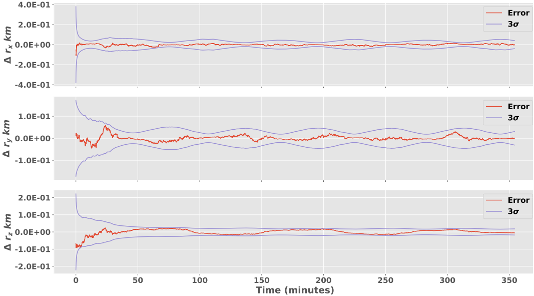
# Time Bias Estimation

- 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

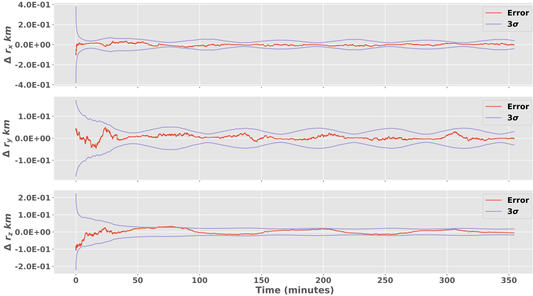


# Time Bias Performance

## 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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