Virtual Research Presentation Conference

Cis-lunar Space Debris Radar and Advanced Signal Processing for GSSR

Principal Investigator: Clement Lee (332K)
Co-Is: Nereida Rodriguez-Alvarez, Joseph Jao, Martin Slade (332K), Kamal Oudhriri (3320)
Program: (Joseph Lazio, Strategic Initiative)
Assigned Presentation #

Jet Propulsion Laboratory
California Institute of Technology

Introduction

Over the years, the Goldstone Solar System Radar (GSSR) has proven to be essential in tracking Near-Earth Objects (NEO) and essential in providing NASA with exclusive orbital debris data in Low Earth Orbit (LEO) via Goldstone's Orbital Debris Radar (ODR), ensuring the safety of astronauts and spacecraft operating in that region of space. With the new focus to send humans to the Moon, there is a need to extend this protection to the Moon and the region in between, cis-lunar space.

This task will adapt the ODR techniques developed for LEO to the cis-lunar space and will perform the necessary tests and studies to prove the use of blind-detection ODR out in cis-lunar space. This task will also further advance the current signal processing capabilities to more complex techniques that allow for better characterization.

The investigation of the cis-lunar SDR detection is a critical step that will support NASA in accomplishing safe travels between Moon and Earth. Modernizing the current signal processing is key to project the GSSR into the future making it capable of more advanced characterization of small bodies and positioning GSSR and the DSN as indispensable elements to protect Earth, Moon and the cis-lunar space and potentially beyond.

Image credit: Purdue University

Problem Description

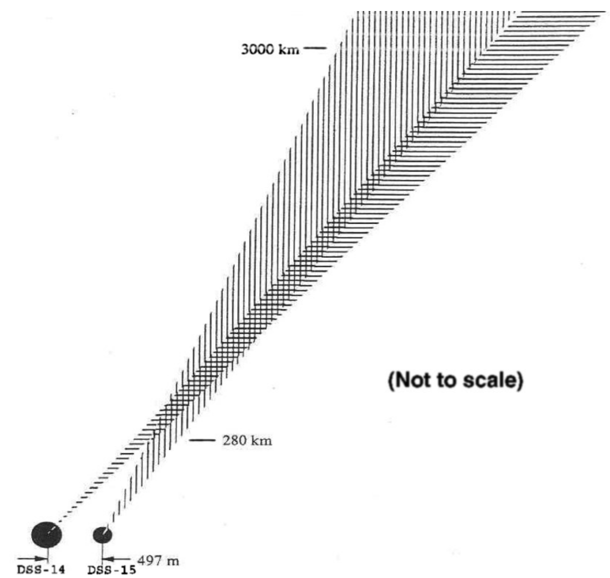
1. Cis-lunar Space Debris Radar (SDR)
   a) The capability of detecting objects in cis-lunar space is becoming more vitally important as there is a new focus to send humans to the moon. Detecting and monitoring objects around the Earth and the Moon helps protect the traffic in the cis-lunar space protecting astronauts and assets.
   b) The Goldstone Solar System Radar (GSSR) has proven to be essential in tracking Near-Earth Objects (NEO). GSSR has been key in providing NASA with exclusive orbital debris data in Low Earth Orbit (LEO) by detecting millimeter scale debris within Goldstone's Orbital Debris Radar (ODR) beam. GSSR has also been involved in locating lost lunar spacecraft Chandrayaan-1 and Ouna.

2. Advanced Signal Processing
   a) Improve the characterization of Cis-lunar space targets by modernizing the signal processing techniques currently applied to the GSSR radar detections and providing a better understanding of the detected bodies.
   b) The GSSR has perform the post-processing of radar track measurements for many years. In general signal processing techniques have advanced and include nowadays denoising and filtering techniques. We aim to bring GSSR to the state-of-the-art of radar processing capabilities.

Both the cis-lunar SDR detection technique and the advanced signal processing techniques will help JPL to become the lead in the capability to detect and characterize small bodies in the cis-lunar space and will suppose a step forward into the efforts that NASA will required to ensure the safety of a spacecraft crossing the cis-lunar space.

Methodology

1. Cis-lunar SDR
   - Adapt the technique for LEO ODR, extending its application out to cis-lunar space.
     - Expertise, infrastructure, hardware, software to perform ODR already exist
       - ODR transmits alternating up and down chirps
         - Takes advantage of delay Doppler coupling of chirps
     - Feasibility analysis (SNR, Doppler, velocity), determine signal appropriate signal parameters for cis-lunar SDR, station geometry analysis
   - Setup experiments to observe known spacecraft or asteroid out in cis-lunar space
     - Check if detection provides correct range, Doppler, size
   - Clutter from the moon likely to be significant issue detecting objects near moon
     - Clutter cancellation to be investigated and implemented
       - Least Mean Squares (LMS), Least Squares (LS)
   - Challenges
     - Much farther, potentially higher Doppler, potentially higher velocity



Sample Goldstone ODR setup
(pre DSS-15 decommissioning)

Methodology

✓ Completed

2. Advanced Signal Processing for GSSR

General code optimization ✓ → **Advanced Processing** → **Denoising Filters**

General code optimization

- Independent code
- Modernized language (Cython with parallel computing)
- Easy to add functionalities

Advanced Processing

- Delay Resolution Enhancement:
  - Flexible sample per baud averaging ✓
- Kalman Filtering (KF)
  - Sequential Extended KF
  - Sequential Unscented KF
- Others

sequentially processes GSSR observations of the debris obtained from the cis-lunar space debris radar detection technique, making use of the target rotation helping reduce the ambiguity of the delay-Doppler maps and would help reduce the error on their characterization.

Denoising Filters

- Wavelet Transform Denoising ✓
- PCA-based Denoising ✓
- Feed-forward Denoising CNN
- Block Matching and 3D Filtering Denoising

solve/mitigate one of the major problems in deriving meaningful texture information, which is the speckle noise

Advanced Processing → **Testing** ← Denoising Filters

Testing

- Previous detections of Chandrayaan-1
- Past NEO tracks
- Debris in the cis-lunar space
- Mini-moons or asteroids passing by
- Future NEO tracks

Testing → **Reporting**

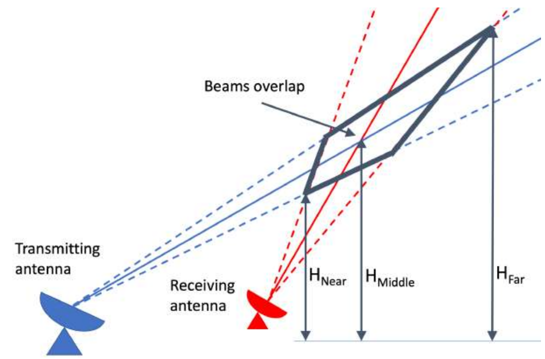
Reporting

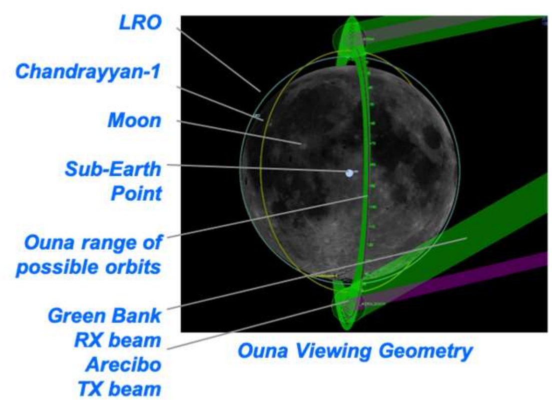
- Summary of techniques and results
- Comparison of results to conventional method
- Documentation
- Publications

Results

Note: This task was less than 1/3 funded, so many objectives were descoped or delay to next FY

1. Cis-lunar SDR
   - 2 SDR applications identified
     - Static pointing similar to LEO ODR (moon must not be in beam path)
       - Search for mini-moons, asteroids, other debris
       - Adapted ODR pointing software to generate Cis-lunar SDR ranges
     - Track a region near the moon
       - More targets available and more value to NASA currently
       - Useful for characterizing lunar orbital debris.
       - Must remove clutter from the moon
       - Plan to repeat experiment pointing 715 km above the lunar north pole, to test clutter cancellation with a ranging signal (up/down chirp) to detect LRO or Chandrayaan-1
   - Cis-lunar SDR waveform developed
     - Transmit composite up and down chirp, full duty cycle
       - Effectively DSB modulation
     - On receive, correlate up chirp separately and down chirp separately
       - Negligible loss in cross correlation
     - Significance: eliminates limitation of receiving two consecutive repetitions for detection

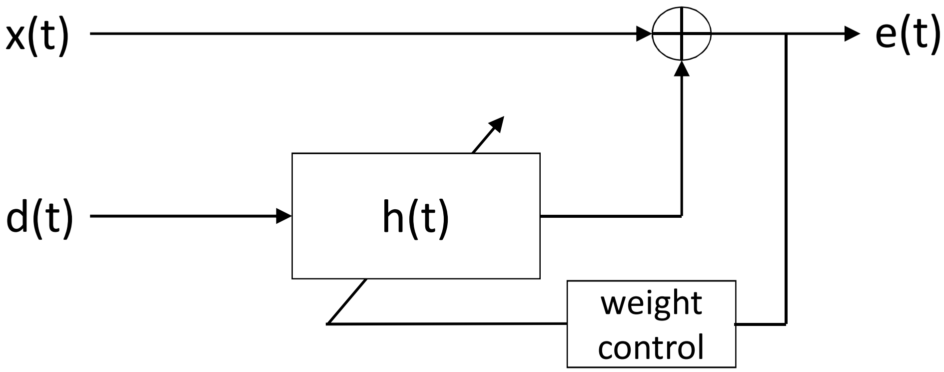


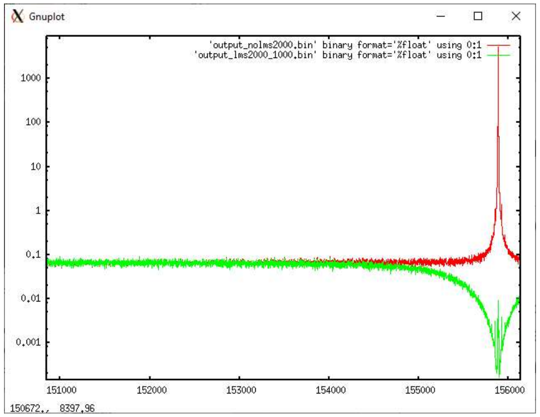


Ouna Viewing Geometry

Results

- Preliminary link budget developed and feasible for potential candidate test targets in FY21
- Clutter cancellation
  - Previous work on lost lunar spacecraft, Ouna, clutter from the moon a significant factor in limitations on pointing and processing
    - Fortunately for CW signal, Doppler on moon is different from expected spacecraft Doppler
    - Will likely be a significant issue for ranging signals
  - Implemented Least Mean Square (LMS) to cancel moon clutter on old Ouna CW data $d(t)=cw(t-RG(t)-\tau)$, where RG(t) is moon ephemeris, τ is delay
    - Can also use for multipath $d(t)=cw(t-\tau)$, (known issue in some bistatic setups)





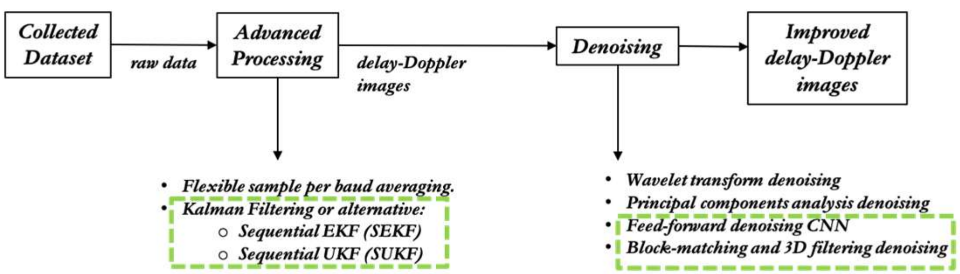
Results

Each image corresponds to a 4 minutes integration.

2. Advanced Signal Processing for GSSR

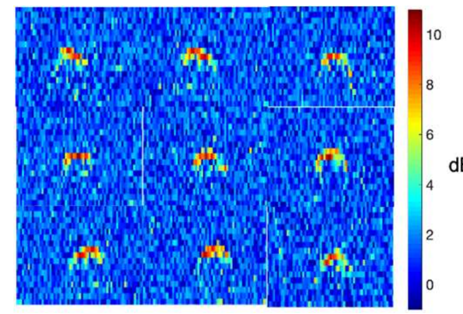
FY2020

Next Steps (FY21&FY22)



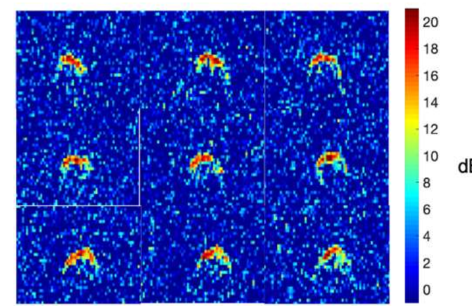
2018 DH1 processed with 1 samples per baud (average every 4 bits) and no denoising

An SNR of 11 dB is achieved.



2018 DH1 processed with 2 samples per baud (average every 4 bits) and PCA-based denoising

An SNR of 20 dB is achieved.



Publications and References

None this FY.