National Aeronautics and Space Administration

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

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Program: FY21 R&TD Strategic Initiative **Strategic Focus Area: Cis-Lunar Space Situational Awareness**

Objectives

1.) Cis-lunar SDR:

- Explore and develop the cis-lunar SDR detection technique: establish the capability to detect and collect data (size, Doppler, range) on objects (mini-moons, lost spacecraft, small asteroids, etc.) out in cis-lunar space.

- Define the limitations and requirements for the standardized use of the cis-lunar SDR detection technique in the future. Investigate how size and velocity of the debris affects the detection and establish the best geometrical configurations and measurement strategies.

2.) Cis-lunar space target improved characterization by modernizing the signal processing techniques (Advanced Signal Processing):

- Development of innovative advanced processing techniques that improve characterization of the debris in the cis-lunar space by improving the SNR.

- Application of the developed advanced processing techniques to NEO in general, not necessarily in the cis-lunar space, expanding the applicability of these techniques to regular tracks.

- Demonstrate the benefits of the advanced processing techniques in real data by re-processing previous tracks and comparing to the results obtained with the existing conventional methods.

- Incorporate the use of the proposed signal processing techniques in upcoming tracks.

Background

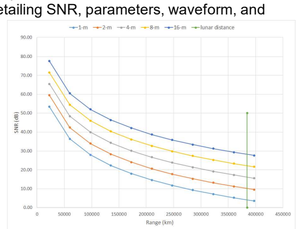
Over the years, the Goldstone Solar System Radar (GSSR) has proven to be essential in tracking Near-Earth Objects (NEO). The United States annual expense in the search for NEO is approximately $4 million, with a focus on tracking those NEO that pose a hazard in potential to impact the Earth. GSSR has also been essential in providing NASA (Office of Safety and Mission Assurance) with exclusive orbital debris data in Low Earth Orbit (LEO) via Goldstone's Orbital Debris Radar (ODR), providing data for the safety of astronauts and spacecraft operating in that region of space. With the new focus to send humans to the Moon, this protection needs to extend to cis-lunar space. The Directorate's Initiative goals include the development and assessment of new detection and processing techniques for the characterization of small spacecraft in the cis-lunar space. GSSR has proven this capability through the detection of the Lunar Reconnaissance Orbiter and lost spacecraft Chandrayaan-1 that were accomplished at JPL in the past years. Small asteroids crossing cis-lunar space may endanger lunar missions. The number of future debris objects in the cis-lunar space will increase as number of missions continue to grow.

Approach and Results

1.) Cis-lunar SDR:

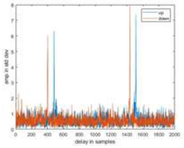
Adapted the technique developed by Goldstein for LEO ODR extending its application out to cis-lunar space. Using existing infrastructure, hardware, and software and the proven LEO ODR technique, we investigated the feasibility of a cis-lunar SDR. A draft report, a deliverable to this task, is near complete, detailing SNR, parameters, waveform, and applications for a cis-lunar SDR.

SNR vs range for Cis-lunar SDR using bistatic DSS-14 to GBT for 0.1 sec. integration time for various size targets.



Several test experiments were setup using bistatic DSS-14 to DSS-13. The initial tests on 2020 SO failed due to operational errors from inexperienced new staff. Another test on Hayabusa-2 also failed likely due to inaccurate pointing information. The final test for the FY on Telstar-401 succeeded in producing correct Doppler estimates and correct apparent range estimate. These initial tests will prepare us for upcoming bistatic DSS-14 and GBT tests with targets near the moon.

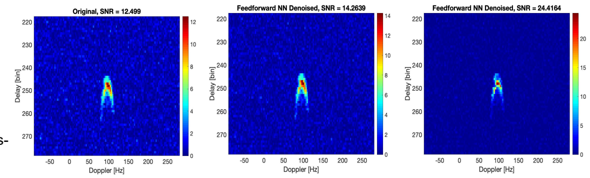
Detection of Telstar-401 using cis-lunar SDR alternating up/down chirp waveform.



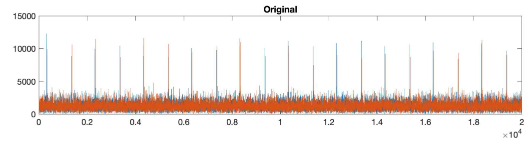
Clutter from the moon will likely be a significant issue detecting any objects near the moon. Least mean Square (LMS) clutter cancellation has been prototyped in software. CW clutter removal works when target and clutter not in the same band. Some ranging data from LRO was used to begin testing. Multipath can be removed easily.

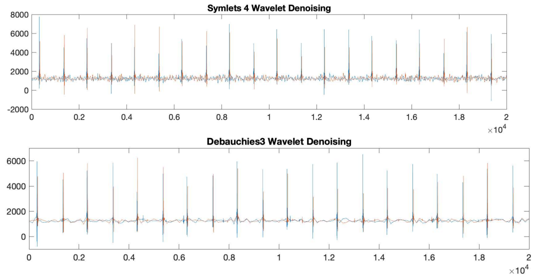
2.) Advanced Signal processing:

To address "application of the developed advanced processing techniques to NEO in general" and "demonstrate the benefits of the advanced processing techniques in real data by re-processing previous tracks and comparing to the results obtained with the existing conventional methods": we continued and completed the study of denoising techniques applied to past NEO tracks. Block-matching and 3D filtering (BM3D) and Feedforward Neural Network (FFNN) denoising techniques were studied and compared to standard GSSR signal processing results. The most effective is FFNN. With little training required, we obtained good noise reduction for groups of 4 raw data files, increasing the final SNR of the averaged datasets: improvements up to x2.2 in SNR (target dependent). We extended the training to a variety of asteroids including low and high SNR and a binary target. We compared the results of the second training to the initial training for a very recent NEO 2016 AJ193. For that particular asteroid with an initial SNR of 12.5, we obtained an improvement of x1.13 with a final SNR of 14.26 (using our initial training) to an improvement of x1.95 with a final SNR of 24.42 (using our second training).



To address "improve characterization of the debris in the cis-lunar space by improving the SNR": we applied denoising to Telstar-401 data, successfully measured with CSDR. The signal shows strong detections and the denoising may not be as critical as it could be for weaker echoes. Nevertheless, we applied two denoising techniques based on wavelets, as we did not have images for this data. The original SNR is 16.28, after denoising employing different wavelets, we obtained SNR improvement up to 34.96.





We have completed a report on the denoising studies including this FY and previous FY. We plan to publish the contents of the report in a peer-review publication.

Significance/Benefits to JPL and NASA

The specific benefits of the two main objectives to NASA/JPL:

1.) Cis-lunar SDR detection of objects will bring a valuable capability for NASA to monitor debris in cis-lunar space and will provide valuable data for potential hazards for future missions to the moon. The capability to blindly detect objects in cis-lunar space does not currently exist. While asteroids are typically detected optically, there may be objects that are in the view of the sun or are optically undetectable. Having the capability to detect these objects via radar, as well as understanding the limitations, will be very useful to NASA.

2.) Advanced signal processing techniques currently applied to the GSSR radar detections provide a better understanding of the detected bodies. This task will enhance the GSSR observational capabilities with advanced signal processing techniques based on extended Kalman filter (EKF) sequential processing and denoising filtering techniques. Those techniques improve the SNR and will bring clearer images of the objects.

Both objectives will help JPL become the lead in the capability to detect and characterize small bodies in cis-lunar space and provide NASA data to ensure safety of a spacecraft crossing cis-lunar space.

References

[1] Brozovic, M. et. al., "Radar Observations of Spacecraft in Lunar Orbit", *Proceedings of the International Symposium of Space Flight Dynamics (ISSFD)*, 2017.

[2] R.M. Goldstein, S.J. Goldstein, D.J. Kessler, "Radar observations of space debris", *Planetary and Space Science*, Volume 46, Issue 8, Pages 1007-1013, 1998.

[3] S.J. Ostro, "Planetary radar Astronomy", *Reviews of Modern Physics*, Vol 65, No 4, Oct. 1993.

[4] C.Lee, et.al., "Micro-Meteroid and Orbital Debris Radar from Goldstone Radar Observations", *International Orbital debris Conference (IOC)*, 2019.

[5] R. Cardinali, et.al., "Comparison of Clutter and Multipath Cancellation Techniques for Passive Radar", *IEEE 2007*.

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Clearance Number:
RPC/JPL Task Number: R20045

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