National Aeronautics and Space Administration

Inter-Satellite Ranging Techniques for Nanosatellites

Principal Investigator: Eric Gustafson (392)
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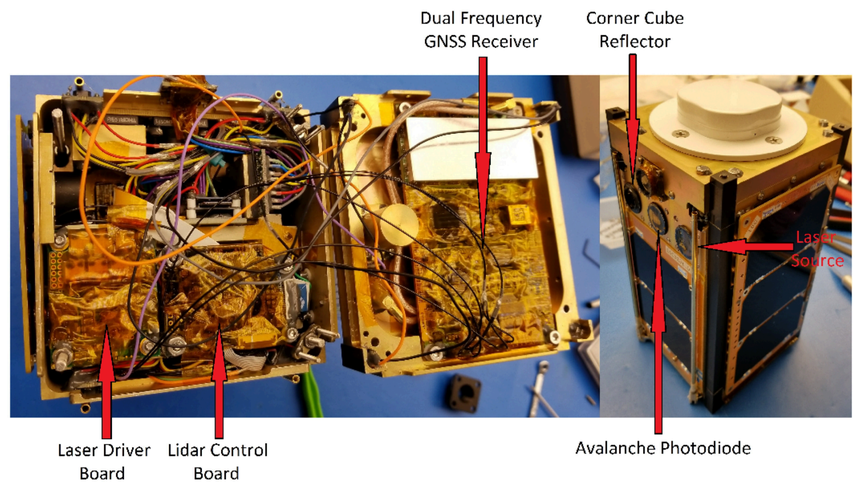
Program: SURP

Project Objective:

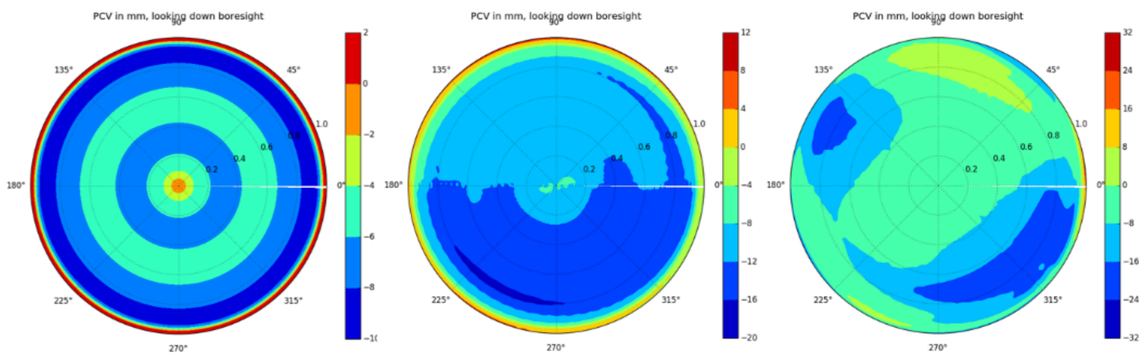
For the FY19 task, Byron Davis (student researcher) completed a summer internship at JPL focusing on the completion of the Monte simulation environment that was begun in FY18. Byron was able to create a full simulation capability in Monte for generation of a constellation's GNSS and inter-satellite range observables, as well as a filtered Orbit Determination (OD) solution observables. Emphasis was placed on building and implementing a high-fidelity error realization for the observables, with characteristic signatures we believe to be congruent with current nanosatellite hardware capabilities.

FY18/19 Results:

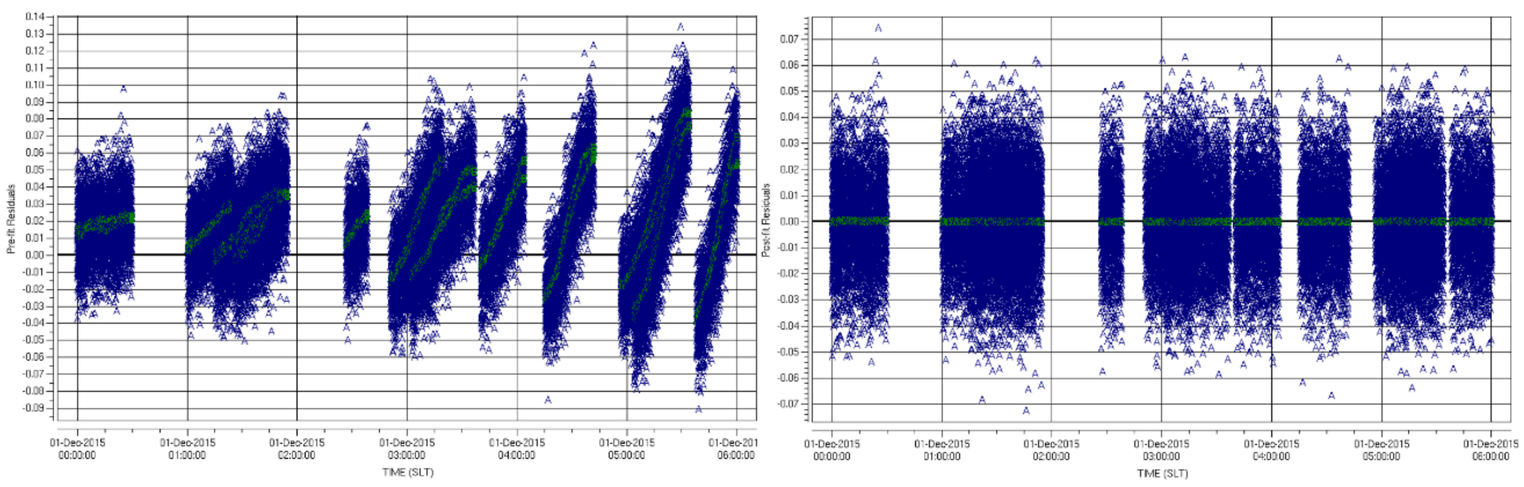


The main achievements during FY19 were the creation of a fully integrated simulation environment, the characterization and simulation of noise sources, and results from an example application. The assessed benefits of utilizing inter-satellite range observables will ideally lead towards the increased utilization of groups of coordinated small satellites (e.g., formations and constellations). Typically, these types of missions require precise knowledge of their position, velocity, and time. Even if GPS measurements are available, inter-satellite ranging can enhance the accuracy, particularly if relative position/velocity are the most pertinent aspects of the navigational needs. Application focus also includes satellite geodesy, and this student research aims to assess the capability of coordinated small satellites to contribute to knowledge of Earth's time-variable gravity field.

One source of potential error was in Phase Center Variation (PCV) mapping error. Manufacturer distributed PCV maps for the GNSS antenna flown on RANGE were only elevation dependent, and we had taken the effort, in conjunction with the Naval Research Laboratory (NRL), to map the PCV at L1 and L2 in NRL's anechoic chamber. From their data, we were able to produce an Azimuth/Elevation ionosphere free combination PCV map for use in our simulations (right figure). Since we were attempting to roll-up total error, we took the difference between this mapping and the manufacturer mapping as the error which should be added to the truth measurements in the simulation. Additional PCV error comes from attitude knowledge error (leading to PCV mis-correction), which was captured by perturbing the attitude of the spacecraft with a realistic time series of attitude error matching what was observed through analysis of the Radio Aurora Explorer-2 (RAX-2) mission.



LC PCV w/o Satellite from NGS Repo | LC PCV w/o Satellite | LC PCV w/ Satellite



The left figure shows the measurement residuals for the GNSS-only case. The residuals are not zero mean before the filter is applied, as expected, and due to some initial orbit error (as well as dynamics error) show some drift leading to increasing error as the simulation progresses in time. After the filter, we see that the residuals become zero mean, with the OD solution (and stochastic parameter estimates) now fitting the noisy measurements in a least-squares fashion. This figure shows that not only is measurement generation working as expected, but that the filter is converging and functioning as well. We see that the filter recovers the trajectory to within 4 cm with GNSS only. With RANGE levels of Inter-Satellite Range (ISR) noise, no current improvement to Precision OD (POD) is seen with leader-follower case initially modeled, nor was any expected (based on previous simulation work).

Benefits to NASA and JPL (or significance of results):

These results are significant in that they show that we have solved the error from last fiscal year (deduced to be a frame overwrite error), and can now produce GNSS and ISR measurements with realistic noise characteristics for any arbitrary constellation, as well as filter a constellation OD solution. The tools are now in place to achieve the primary goal of this study, which is to determine what gains to POD these ISR measurements provide.

*Many thanks to Dr. Jill Seubert for providing the basis of the GPS measurement modeling within Monte

Publications:

1. Davis, B. T., and Gunter, B. C., "The Augmentation of Precision Orbit Determination through Constellation Intersatellite Ranging," Proceedings of AIAA Space Conference, Long Beach, California, 2016
2. Davis, B. T., and Gunter, B. C., "The Impact of Inter-satellite Range Measurements on the Orbit Determination of Satellite Constellations," Proceedings of the AAS/AIAA Astrodynamics Specialist Conference, Vail, Colorado, 2015

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