Orion Relative Navigation Flight Software Analysis and Design

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The ability to successfully perform rendezvous has been the cornerstone of US manned space exploration since its inception. And at the heart of the execution of rendezvous has been ability to perform relative navigation with respect to the target. Over these many decades, as computer and sensor technology have advanced, the function of relative navigation has both become easier and become more challenging. Better computational resources are not imposing the harsh demands on precision as they were thirty years ago. At the same time, sensors provide a great deal more information in terms of images and this means that computational resources are in increased demand with respect to image processing. Any relative navigation system designed today makes use of sensors such as Lidars, imaging star trackers all of which provide relative navigation but require processing throughput, though many of these sensors do their own processing internally.

The Orion relative Navigation System has sought to take advantage of the latest developments in sensor and algorithm technology while living under the constraints of mass, power, volume, and throughput. In particular, the only sensor specifically designed for relative navigation is the Vision Navigation System (VNS), a lidar-based sensor. But it uses the Star Trackers, GPS (when available) and IMUs, which are part of the overall Orion navigation sensor suite, to produce a relative state accurate enough to dock with the ISS.

The Orion Relative Navigation System has significantly matured as the program has evolved from the design phase to the flight software implementation phase. With the development of the VNS system and the STORRM flight test of the Orion Relative Navigation hardware, much of the performance of the system will be characterized before the first flight. However challenges abound, not the least of which is the elimination of the RF range and range-rate system, along with the development of the FSW in the Matlab/Simulink/Stateflow environment. This paper will address the features and the rationale for the Orion Relative Navigation design as well as the performance of the FSW in a 6-DOF environment as well as the initial results of the hardware performance from the STORRM flight.

Whereas, the first missions of Orion are being planned to the ISS, the relative navigation system makes no assumptions as to the central body of the rendezvous. In particular, it has been designed to also operate outside of LEO. As such, it is not reliant on the GPS constellation for its accuracy.

The Orion Relative Navigation System is designed to operate from when the two vehicles are more than 300 km away from each other to all the way to dock. As such the system incorporates various kinds of measurements, from ground updates, to star tracker angle measurements to LIDAR measurements (range, bearing). As one might expect, IMU measurements are used to propagate states when no relative measurements are available. Additionally, Orion GPS measurements, when available, are used but only the PVT is used. This was done to simplify the relative navigation design, and to occasionally anchor the inertial translation states

The dual-inertial state filter that is used is flexible enough that accurate inertial states are not crucial. In fact, in LEO, GPS measurements are inhibited during the prox-ops phase; hence the inertial states may drift but the relative states remain accurate because of the accuracy of the LIDAR system. Many of the challenges involve the ability of the system to handle latent measurements. A high-order gravity field is used to propagate both the target and Orion states. Because it is design to operate all the way to dock, both relative translation states and relative attitude states are necessary. Two different filters, a relative translation filter (RTFILT) and a relative attitude filter (RAFILT) have been designed and implemented.

The translation relative navigation filter (RTFILT) operates at 1 Hz, using buffered IMU data. The relative attitude filter (RAFILT) operates at 5 Hz. But this filter (RAFILT) only operates during the final 20 meters of the rendezvous/proxops phase.

In the earlier phase of the design, Linear Covariance analysis was used to evaluate the performance of the relative navigation system design. This methodology allowed sensitivity analyses to be done and allowed trade studies to be quickly performed. As the design has matured, the design has been implemented the Matlab/Simulink environment, primarily in eML, as part of the flight software process. As part of this exercise, some of the metrics like cyclomatic complexity, have spurred improvements to make the algorithms more efficient, both in terms of SLOCs and in terms of arithmetic operations (multiplies/divides, adds/subtracts). These improvements have resulted in more efficient flight code.

Monte Carlo analysis is now being used to evaluate not only the relative navigation performance but also the overall rendezvous performance. Thus, the guidance, navigation and control functions are exercised to provide the overall system performance.

This paper will discuss the design of the Orion Relative Navigation system as well as present the Monte Carlo results that will demonstrate its performance.