IAF SPACE EXPLORATION SYMPOSIUM (A3)
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CAPSTONE: A HIGHLY SUCCESSFUL MISSION DEMONSTRATING AUTONOMOUS NAVIGATION AND OPERATIONS TECHNOLOGIES IN THE CISLUNAR DOMAIN

Abstract

Advanced Space, Terran Orbital, Rocket Lab, Stellar Exploration, JPL, the Space Dynamics Lab, Tethers Unlimited, and NASA have partnered to develop, launch, and operate the Cislunar Autonomous Positioning System Technology Operations and Navigation Experiment (CAPSTONE) mission, which is serving as a dedicated precursor for Near Rectilinear Halo Orbit (NHRO) operations in cislunar space. Over the past 28 months, this low-cost, high-value mission has demonstrated an efficient, low-energy orbital transfer to the Moon, a successful insertion into the NRHO, and 23 months of successful operations in the NRHO while demonstrating key technologies in support of the NASA Artemis lunar exploration program. These technologies include 1) The CAPS autonomous navigation technology using both two-way ranging with the Lunar Reconnaissance Orbiter (LRO) and one-way uplink ranging with the Deep Space Network (DSN) 2) Demonstration of our Neural Net for Electric Propulsion (NNEP) technology for autonomous maneuver planning and execution and 3) Demonstration of our Sigma Zero technology for spacecraft anomaly detection and classification.

The Cislunar Autonomous Positioning System (CAPS) is a peer-to-peer real-time system for autonomously estimating absolute position and velocity for spacecraft operating in the cislunar environment. The CAPSTONE spacecraft has executed multiple successful ranging passes with LRO and validated onboard the CAPS algorithm performance. The software has also been used to estimate absolute navigation states using one-way uplink ranging signals to the SDL Iris radio combined with a high-precision Chip Scale Atomic Clock (CSAC) and algorithms provided by JPL.

NNEP is a maneuver design algorithm that uses neural networks as function approximators to map the current state of a spacecraft to a corresponding maneuver. The onboard test on CASPTONE demonstrated a neural network trained to design the orbital maintenance maneuvers (OMMs) for CAPSTONE.

Sigma Zero performs anomaly detection and classification via a neural network model. CAPSTONE has executed the onboard test of this software, downlinked the neural network output as telemetry packets, and verified that the result matches what was expected. The onboard testing used data generated on the ground to correctly identify a maneuver mismodel in Kalman filter post-fit residuals. Subsequent testing was executed to identify and autonomously classify eight additional types of anomalies.

This presentation and paper include an overview of this NASA technology focused mission, lessons learned from the 2+ years of successful operations, a summary of the challenges encountered, and an overview of the results from the CAPS, NNEP, and Sigma Zero autonomous navigation technology demonstrations.