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CISLUNAR AUTONOMOUS NAVIGATION USING MULTI-GNSS AND GNSS-LIKE AUGMENTATIONS: CAPABILITIES AND BENEFITS

Abstract

Global Navigation Satellite System (GNSS)-based autonomous navigation has the potential to dramatically expand lunar exploration capabilities. Over the past two decades, GNSS users in Low Earth Orbit (LEO) have realized reduced recovery time after maneuvers; improved operations cadence; increased satellite autonomy; and more precise, real-time navigation and timing performance. Recent flight results suggest that the capabilities afforded by GNSS in LEO can be extended to cislunar space.

Based on the operational GPS data acquired from the Magnetospheric Multiscale (MMS) mission, with orbit apogee exceeding 40% of lunar distance, it is clear that GPS can play an important role in the outbound and return phases of a lunar mission. Furthermore, simulations based on MMS data have shown that GPS reception can be extended to lunar distances by augmenting existing high-altitude GPS navigation systems with a higher-gain antenna. These simulations have demonstrated at lunar distance at least one signal visible 99% of the time, four or more visible out to 55 RE, kilometer-level range errors, and 100 meter-level lateral errors (3 sigma).

This paper presents a trade study that extends the current, published understanding of expected GPS performance in cislunar space to include interoperable multi-GNSS signals from all 4 GNSS constellations (GPS, GLONASS, Galileo, and BeiDou) and the regional augmentations (NavIC and QZSS). An initial comparison is made between single and multi-constellation cases using the constellation properties defined in Space Service Volume (SSV) booklet produced by the United Nations' International Committee on GNSS (ICG). The ICG has developed an internationally-accepted definition of the multi-GNSS SSV—the volume of space around Earth from 3,000 km altitude to 36,000 km. The booklet definitions are conservative, however, so these results are compared to higher-fidelity simulations that include more accurate transmit antenna patterns, such as measured GPS patterns from the GPS Antenna Characterization Experiment (GPS ACE).

This paper also considers the use of selected GNSS augmentations that can provide higher power and improved geometry. These can include pseudolite signals from the lunar surface or from space agency assets in cislunar space. This paper surveys relevant literature and describes how these extensions can improve navigation and timing performance. Projected benefits are evaluated against the feasibility of implementation. The advantages of employing this autonomous navigation capability in cislunar space are discussed, and a survey is given of the types of missions, including the Lunar Orbiting Platform-Gateway, that could benefit from this extended capability.