National Aeronautics and Space Administration

FY24 R&TD Innovative Spontaneous Concepts (ISC)

Case study of a single-satellite lunar navigation system using Iris transponder's inter-spacecraft ranging, providing 15m or better in-situ user positioning on the lunar surface

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Strategic Focus Area: Innovative Spontaneous Concepts

Objectives: Our objective was to investigate a lightweight and minimalist lunar in-situ navigation satellite system utilizing JPL transponders.

Background:
Radiometric navigation is considered a key service for next-generation lunar surface missions. The proposed minimalist approach uses **a single orbiter and surface reference receiver** (**Figure 1**).

The process involves: 1) collecting **dual 1-way ranging (DOWR)** measurements for clock-bias-free data, reducing the need for high clock stability, 2) using the single-differenced process to effectively cancel out common errors, and 3) optionally utilizing a digital elevation model (DEM) to compensate for insufficient three-dimensional satellite geometry coverage.

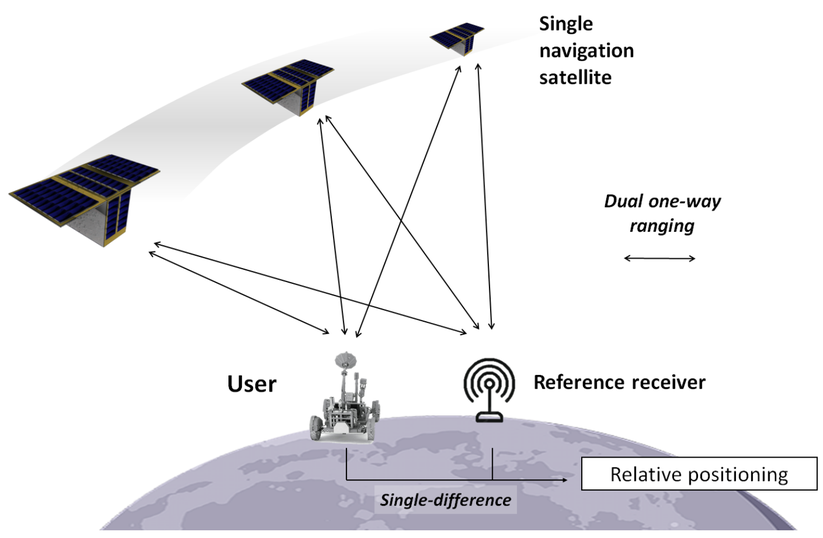

Figure 1. Proposed Single-Satellite Navigation.

Approach and Results:

- This research selected a connecting ridge that exists near the Shackleton crater at South pole for the location of the simulated user/reference receiver and the satellite geometry including a 300-km altitude with 70° and 80° inclinations, a 600-km altitude with an 80°inclination, and a 12-hour elliptical lunar frozen orbit (ELFO) orbit for performance comparison (**Figure 2)**.
- Concurrently, we accounted for hardware and software constraints based on the current capabilities of JPL's transponders, using two different over-the-air RF powers (OVA): 1 W and 10 W, three loop bandwidths (LBW): 1 Hz, 10 Hz, and 100 Hz, and a Chip-Scale Atomic Clock (CSAC). Pseudorange observations were provided to both the user and the reference receiver at 30-second intervals throughout the entire ground pass while the satellite was in view.

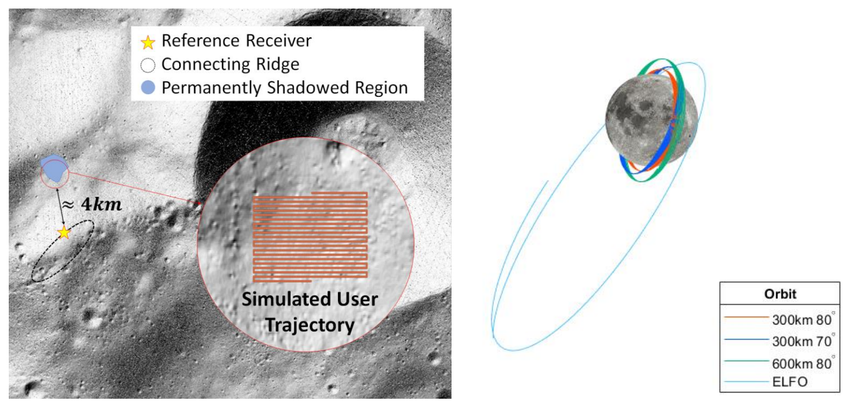

Figure 2. Simulated User and Satellite Geometry.

The results (**Figure 3**) suggest that the 300 km-70° orbit offers the best user positioning accuracy, despite its shorter observation period, due to the rapid changes in satellite geometry. For instance, with a 1-W OVA and 1-Hz LBW, the obtained 3RMS positioning accuracy was **16.7 m** for 3D positioning and **14.4 m** for DEM-aided positioning, based on 12 minutes of observation. **Figure 4** illustrates the transition in user positioning accuracy and dilution of precision (DOP) during a single ground pass for the corresponding case.

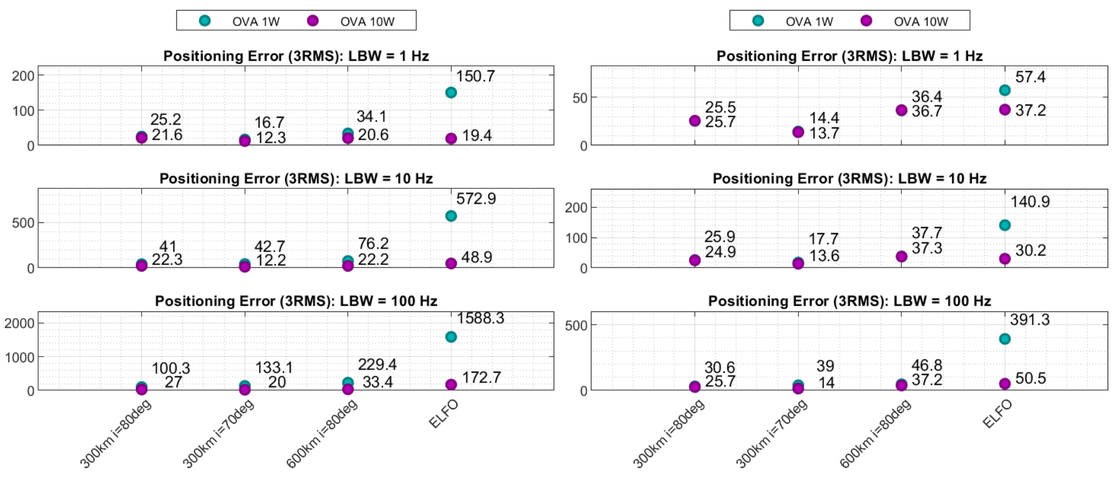

Figure 3. Three Root Mean Square (3RMS) User Positioning Accuracy: (left) 3D Positioning (right) DEM-Aided Positioning.

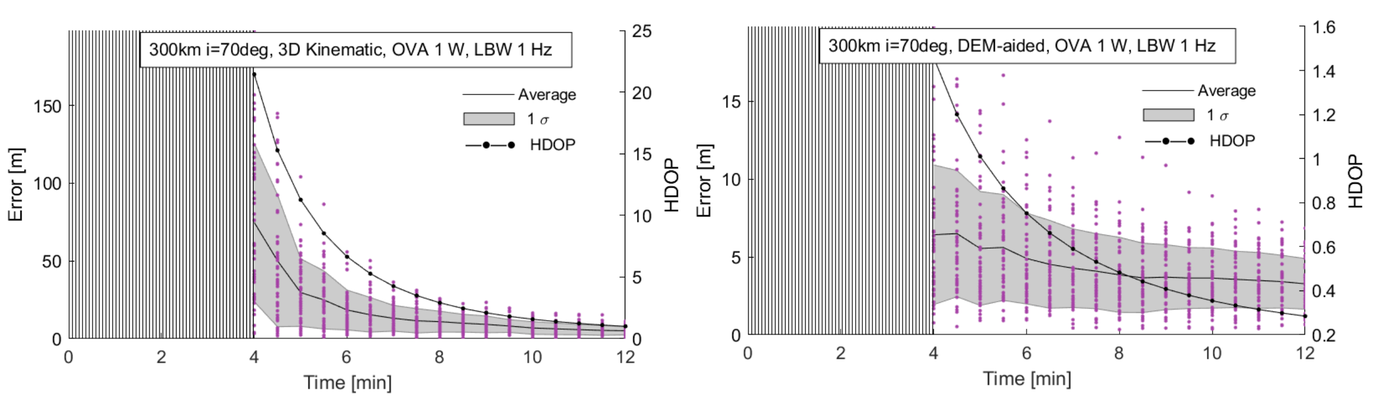

Figure 4. DOP and User Positioning Accuracy for the 300 km-70° case with 1-W OVA and 1-Hz LBW: Purple dots show data from 50 simulation runs. The left side shows 3D positioning, and the right side shows DEM-aided results. *Please note that the vertical axis ranges differ between the two scenarios.*

Significance/Benefits to JPL and NASA:

- The results indicate that placing a single navigation satellite in a Low Lunar Orbit (LLO) can improve user positioning speed and accuracy. While an ELFO configuration is ideal for larger navigation constellations aimed at long-duration coverage, **adding a lightweight satellite in LLO can enhance global system performance and provide regional backup**.
- The results highlight the critical role of a lunar surface reference receiver. Using the single-difference method effectively eliminates common errors, like satellite ephemeris inaccuracies, reducing the need for frequent orbit determination and time synchronization with Earth-based stations or GNSS.
- The study also shows that the CSAC, or even a lower-grade clock, can provide sufficient stability for navigation system. Reducing Size, Weight, and Power (SWaP) requirements could lower launch cost and increase deployment options for various orbits or as a complement to larger constellations..

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Publications:

Lunar Surface Positioning Using a Single-Satellite Navigation System with Single-Difference Dual One-Way Ranging (in progress)

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