PRACTICAL RENDEZVOUS SCENARIO FOR TRANSPORTATION MISSIONS TO CIS-LUNAR STATION IN EARTH-MOON L2 HALO ORBIT

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ABSTRACT

This study addresses a guidance and navigation strategy and rendezvous trajectory design for transportation missions to the cis-lunar space station in Earth-Moon L2 halo orbit.
The updated Global Exploration Roadmap delivered by International Space Exploration Coordination Group (ISECG) is outlining strategies for the human and robotic exploration to the Moon, Mars and beyond. A new international space station in the vicinity of the Moon draws attention as a potential gateway for future missions. Assuming such station to be constructed, various rendezvous missions, such as logistics flight and crew transportation missions, will be performed. In LEO, many rendezvous missions have been carried out such as HTV and ATV for ISS, and the rendezvous operation technology has been highly established. However, in cis-lunar orbits, the dynamics of relative motion is different from that in LEOs, and the navigation scheme based on GPS, which is the key navigation method in LEO rendezvous missions, can not be applied. Hence different kind of rendezvous scheme is necessary for application to rendezvous missions in cis-lunar orbits.
In this study, a practical rendezvous scenario for transportation missions to the cis-lunar space station is suggested and the problems and requirements regarding Guidance, Navigation and Control (GN&C) for the deep-space rendezvous are clarified. Among various cis-lunar orbits, an Earth-Moon L2 halo orbit is applied to this study as one of the major candidates for the station orbit. Figure 1 shows the overview of the scenario as viewed in the station-centered Earth-Moon rotating frame. The pink line indicates the trajectory of the visiting vehicle and the two circles labeled as “Approach Sphere” and “Keep Out Sphere” are predefined safety regions.

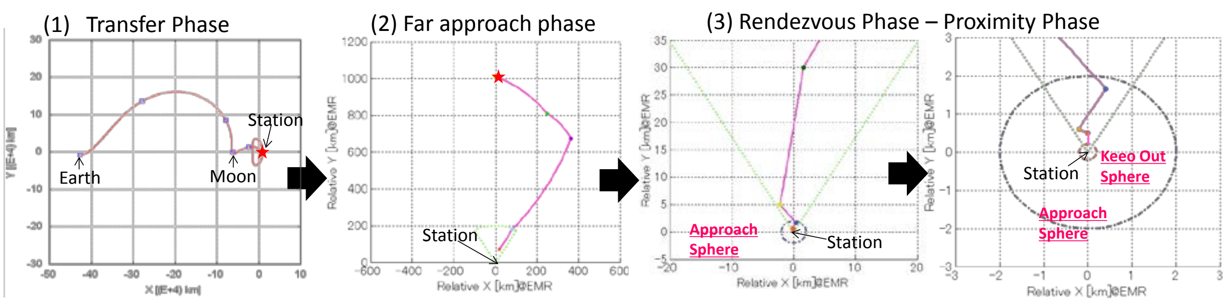

Figure 1. Example of trajectory design for cis-lunar rendezvous mission

The scenario is divided into four phases: 1. Transfer phase, 2. Far approach phase, 3. Rendezvous phase, and 4. Proximity phase. First, in the transfer phase, the visiting vehicle departs from LEO and is inserted into the halo orbit at a certain distance from the station via powered lunar swing-by. Three major maneuvers are conducted for the transfer; at LEO departure, lunar swing-by, and halo orbit insertion. In this phase, the navigation state is determined by a ground based tracking system and the maneuver planning is conducted in ground stations. Second, in the far approach phase, the visiting vehicle flies along with the nominal trajectory through an implicit guidance scheme and approaches to the point in relative distance of approximately 200 km, at which the onboard relative navigation sensor starts operation. Then, it slowly moves closer to 100 km point with evaluating the relative navigation data. Third, in the rendezvous phase, the navigation switches to the relative navigation based on the onboard relative navigation sensor from the absolute navigation based on the ground stations. The control maneuvers in this phase are planed onboard the spacecraft. In this phase, the visiting vehicle goes through several intermediate points and arrives at the point several hundreds meters away from the station. Lastly, in the proximity phase, a high-precision relative navigation sensor starts operation and the visiting vehicle approaches at several ten meters distance to the station. The closed-loop trajectory control is applied in this phase. In the transfer and far approach phases, 2-way range, 2-way Doppler, and 3-way Doppler data collected by the tracking operation at Usuda Deep Space Center in Japan and NASA's Deep Space Network are assumed to be used for the absolute navigation. For the relative navigation in the rendezvous phase, it is assumed that the LOS angle data from a visible camera and ranging data by proximity communication equipments onboard both the visiting vehicle and the station are utilized. In the proximity phase, an onboard LIDAR is supposed to be a major candidate.

Based on the relative navigation analysis, trajectory design is performed considering following four guidelines. First, passive abort should be safe, that is, the free drift trajectory including its dispersion should not intercept a certain safety region around the station. Second, fuel consumption should be feasible. Third, the total flight time should be reasonably short and timings of operational events such as maneuvers and evaluation of navigation data should be practical from the perspective of real flight operation. Forth, within the distance of less than about 200 km, the visiting vehicle should move in a cone-shaped region extending from the station, which corresponds to the supposed field-of-view of the radar onboard the station. Numerical simulations have been carried out to evaluate the safety of the rendezvous scheme considering navigation filter algorithm, targeting algorithm, sensor models, and maneuver errors. As shown in the Figure 2, free drift trajectories are confirmed to be safe.

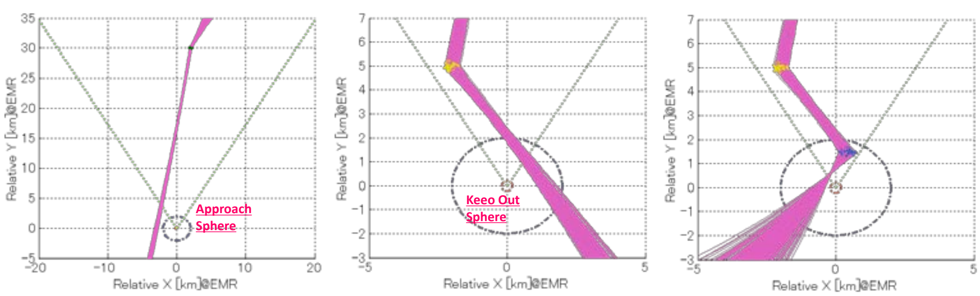

Figure 2. Example of trajectory safety analysis. Free drift trajectories do not intersect the predefined safety regions.

In this paper, we also address a concept to install an active navigation system (e.g. X-band radar) to the cis-lunar space station and provide the mission supportive data from the station to the visiting vehicle through the proximity communication. This concept would simplify the system design of visiting vehicles, minimizing overall development and operation cost while safety and robustness being retained at sufficient level or, moreover, improved.