NAVIGATION AND TRAJECTORY DESIGN FOR JAPANESE ACTIVE DEBRIS REMOVAL MISSION

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ABSTRACT

Space debris is now recognized as a serious environmental problem. Even if all launches were stopped immediately, the debris population would increase as a result of in-orbit collisions. Liou [1] claimed that active removal of large and massive debris placed in crowded orbits is effective to prevent the collisions which are major causes of the increasing tendency. JAXA studies electrodynamic tether (EDT) system as one of candidate devices for the active debris removal (ADR) mission [2]. The EDT is a propulsion system that can transfer large objects without the need for the propellant by using interaction with the Earth's geo-magnetic field. A launch vehicle upper stage is considered as a primary target. To achieve the mission, a chaser spacecraft has to approach to the non-cooperative target and attach an anchor mechanism, which is located at the tip of the tether, on the target. In this paper, results of navigation and trajectory design for the ADR mission are presented. Figure 1 shows an overview of a rendezvous scenario of the mission.

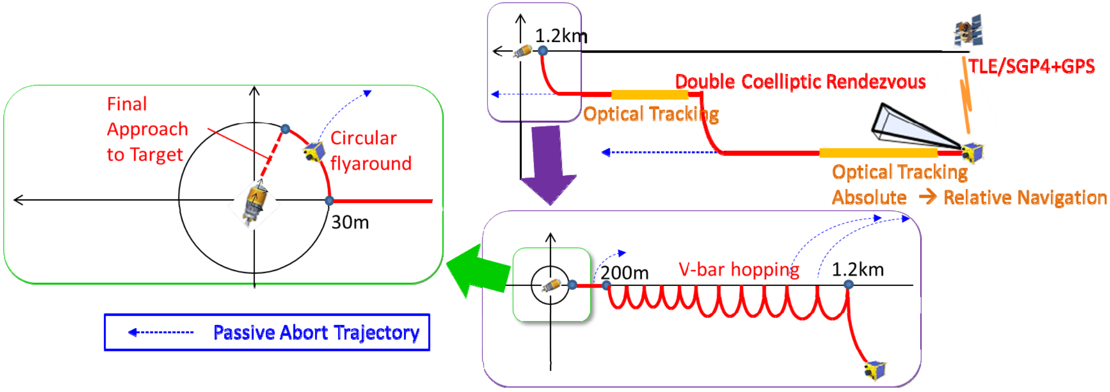

Figure 1. Rendezvous scenario for the active debris removal mission

First, the chaser spacecraft starts far-range rendezvous by using TLE/SGP4 as target debris orbit information. Second, the target is detected by onboard cameras, then relative navigation is initiated. In this phase the target is imaged as a so small dot that angles-only navigation (AON) is performed. Third, the spacecraft rises its altitude to V-bar, and approaches to the target applying a v-bar hop. Fourth, it stopped at 30 m distance and target pose-estimation is performed. Fifth, it maneuvers above the payload attach fitting (PAF) of the target applying a circular fly-around. Then it approaches to the PAF and inserts the anchor mechanism in it.

A visible camera, an infrared camera, and a LIDAR are supposed to be candidate types of navigation sensors for the mission. A visible camera can detect the target from very far distance, but its detectability strongly depends on illumination condition and target surface properties. Furthermore, a visible camera is not available during night at far distance where onboard flashlight is not effective. An infrared camera is so insensitive to illumination condition that it can be expected as a reliable navigation source throughout the mission. A LIDAR is also insensitive to illumination condition and it can measure relative distance directly. Analysis on functionality and performance of these types of candidate navigation sensors is performed to characterize its features and select the best combination of sensor types for the mission.

Based on the relative navigation sensor analysis, trajectory design is performed considering following three guidelines. First, passive abort should be safe. Second, observability of AON should be confirmed. Third, fuel consumption should be feasible. The space shuttle is a typical mission which approaches to its target applying AON as a primary navigation method. According to Goodman [3], the nominal approach trajectory of the space shuttle was double coelliptic rendezvous (DCR) until 1983, afterwards it changed to stable orbit rendezvous (SOR). A trade-off study is performed and the DCR is selected as the nominal approach trajectory considering passive abort safety to be important, since relative navigation to a non-cooperative target is supposed to be sometimes unreliable. Analysis on mechanism of AON observability is also performed and the trajectory is designed so that observability can be confirmed.

For demonstration of the navigation and trajectory analysis, a numerical simulation has been carried out. AON Kalman filter algorithm, navigation sensor models, and actuator models are implemented in the simulation. Navigation error difference between the DCR and the SOR has been evaluated. In addition, navigation error difference due to selection of navigation sensor types is assessed, and the proper combination for the ADR mission is discussed.

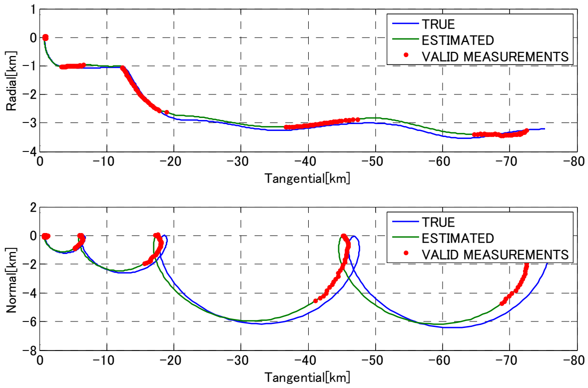

Figure 2. Rendezvous trajectories (top: DCR, left: SOR, blue:true, green:estimated, red: a point where valid measurements of visible cameras are available)

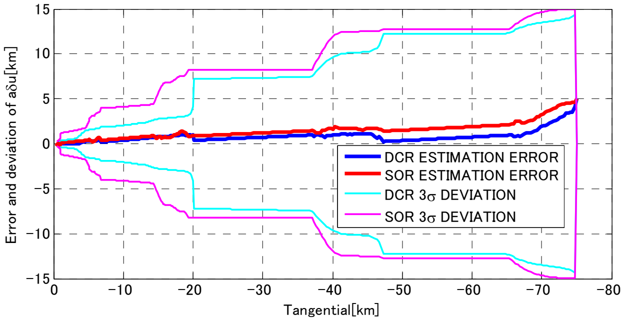

Figure 3. Comparison of navigation error and its 3-sigma deviation in tangential direction between DCR and SOR

References

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