GPS NAVIGATION SYSTEM FOR CHALLENGING CLOSE-PROXIMITY FORMATION-FLIGHT

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ABSTRACT

The PRISMA mission represents a great milestone in the history of autonomous formation flight. A large amount of data and experience has been collected during the mission lifetime, constituting an inestimable treasure of know-how for future distributed spacecraft systems. Among the notable achievements of the mission, the GPS navigation system contributed by DLR has proven its great value by supporting continuously the formation with accurate and robust real-time navigation.

The PRISMA GPS navigation system was composed of an onboard navigation filter running on the main spacecraft and collecting GPS measurements from the Phoenix GPS receivers embarked by the two spacecraft of the formation, in order to derive in real-time an accurate absolute and relative navigation solution. Both spacecraft were equipped with a dual-antenna system, allowing the selection of the best visibility of the GPS constellation by switching autonomously the active antenna. Thanks to its high technology readiness level, the GPS navigation system could be successfully used to monitor in real-time the safety of the formation and has also served as independent reference for the calibration and verification of other sensors.

Overall, the GPS navigation system demonstrated impressive performance, providing relative navigation accurate at the centimeter level in some favorable cases. However, some of the close-proximity formation-flying scenarios exercised by PRISMA have posed many difficulties for the GPS-based navigation. First, intensive maneuvering activities are usually required during the close proximity operations, perturbing the onboard dynamical filtering based on precise modelling of the relative dynamics. In addition, an optimal visibility of the constellation cannot be always guaranteed when the spacecraft are experiencing large attitude changes, especially if one of the two spacecraft is tumbling. Finally, the antenna switches result in short tracking interruptions, which can greatly reduce the quantity of available measurements and thus affect the robustness and accuracy of the navigation solution if these switches are too frequent.

This explains the degradation of navigation performance which has been observed during some forced-motion PRISMA scenarios in which one spacecraft was tumbling. The behavior of the onboard navigation system could be party improved post-facto by tuning the navigation filter, but it was not enough to always ensure accurate and robust navigation. In fact the main limitation comes from the reduced common visibility of the GPS constellation in some unfavorable cases. The onboard navigation filter uses differenced carrier-phase measurements to reach accurate relative navigation, which requires a high number of GPS satellites commonly seen by both spacecraft. Collecting many differenced measurements is also important to ensure the robustness of the navigation solution during forced-motion and in the presence of multipath. The PRISMA navigation

system is mainly limited by the fact that, even if every spacecraft is equipped with two antennas, only one antenna can be used at once. In some scenarios, the antenna boresight of one spacecraft might point to a direction normal to the boresight of the antenna of the other spacecraft, reducing dramatically the common portion of sky visible by both spacecraft and thus weakening the navigation solution derived onboard.

Future formation flying missions envisioning forced-motion close-proximity operations with tumbling spacecraft would thus need to adapt the architecture adopted in the PRISMA mission by enforcing an omnidirectional tracking capability of the spacecraft to improve the common visibility. The paper discusses the main options available to solve this issue and presents the retained solution, consisting in using two independent GPS receivers covering simultaneously two different hemispheres instead of only one. Minor adaptions of the PRISMA flight software would be necessary to fuse the measurements coming from the different receivers. The architecture presented in the paper is validated by highly realistic simulations of typical close-proximity scenarios (e.g. v-bar and r-bar docking or inspection flight) during which the spacecraft are intensively maneuvering and are subject to large variations of attitude. The paper presents the main simulation results and demonstrates the benefits offered by the retained approach. Overall real-time relative position error below 10±20 cm on each axis of the orbital frame and relative velocity error below 0.2±2 mm/s can be reached.