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Autonomous LEO navigation with single-frequency GPS receivers: Application of multipath mitigation techniques

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Precise real time LEO satellite positioning is becoming an important aspect for several satellite applications such as Autonomous Formation Flying (AFF) and Space Rendezvous and Docking (RVD), where the own LEO satellite must take autonomous decisions. Many launched satellites are equipped with GPS receivers which can be used for these kind of maneuvers.

In this sense, dual-frequency receivers allow a more precise positioning than single-frequency ones. The reason of this is because the ionospheric delay of the signal (one of the most important error sources, even on LEO altitudes) can be removed by a specific combination of both frequencies. In single-frequency processing, this ionospheric term can also be removed (by means of the GRAPHIC combination), but at a cost of an increased noise in the observable, mainly due to multipath errors.

The multipath affecting the signal of LEO satellites mainly comes from reflections on the own spacecraft body. So, by identifying a reference frame which follows the attitude of the spacecraft, it is possible to get repeatable multipath patterns. This reference frame also receives contributions from crosstalk interferences from other GPS antennas, which of course, are fixed to the spacecraft and also follow its attitude.

The technique is based on the apriori analysis of the filter residuals of a precise post-process dynamic orbit determination of the satellite. From these residuals it is possible to extract a multipath characterization of the environment of the satellite, assigning a

value of expected multipath for a set of azimuth/elevation directions (multipath map). Simultaneously, it is also computed a sigma value for each of the directions in order to use it as a weight factor in the real-time positioning (weight map). Both maps are applied in the real time LEO dynamic positioning (if the spacecraft attitude is sufficiently known) to correct the single frequency measurements obtaining an observable with lower noise and a corresponding weight for the position filter.

This multipath mitigation technique has been applied to four different satellites in order to test its effectiveness: CHAMP, SAC-C, JASON and GRACE-A, with different kind of orbit and clock data: broadcasted, precise products (obtained in postprocessing, consequently unavailable in real-time, but done as reference for comparison purposes), and a real-time GPS clock estimation (with a set of ground stations with global coverage). Different levels of success of 3D position enhancements have been achieved ranging up to 33% in precise and real-time GPS clock estimation (obtaining between 15cm and 25cm of 3D RMS error), and up to 13% in broadcasted products (between 50cm and 60cm) comparing to single-frequency unmitigated positioning.

This algorithm could be implemented and used on board of LEO satellites in order to enhance its own positioning. It approaches the behavior of single-frequency receivers to dual-frequency ones, and the results depend mainly on the orbit and clock products and on the specific satellite multipath environment.