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A SIGNAL PROCESSING APPROACH TO GNSS PRECISE POSITIONING FOR LUNAR EXPLORATION

Abstract

In order to facilitate next generation human-occupied lunar bases and to accelerate space exploration, there is a need for an economic approach to resource management. Actually, in recent years there is an increasing interest from several space agencies, including NASA and ESA, in the use of Global Navigation Satellite Systems (GNSS) for space exploration, and more specifically to provide precise and reliable positioning to spacecrafts exiting the atmosphere, and eventually to exploit GNSS as a positioning system on the Moon. In this contribution we address the feasibility of using existing GNSS technology for precise navigation on lunar bases, as well as for the localisation and guidance of spacecraft intended for lunar visits.

GNSS were designed to operate under clear-sky conditions on Earth, then their performance is severely degraded under harsh propagation conditions such as multipath, non-line-of-sight (NLOS) or interference (jamming/spoofing), as well as high receiver dynamics and weak signal conditions. Besides these particular working conditions, inherent GNSS sources of error such as clock drifts or atmospheric delays, make that standard GNSS positioning (SPP) error is of the order of some meters. Different approaches have been developed to provide high-precision centimetric positioning, with a potential technique for space exploration being Precise Point Positioning (PPP), based on multi-frequency code and carrier-phase measurements. The advantage is that PPP can obtain sub-decimeter errors without requiring reference stations in proximity. However, its performance and convergence time depends on the constellation geometry, and needs the availability of precise clock and orbit products.

In these scenarios, the aforementioned propagation conditions and interferences on the Earth's surface do not apply, but the spacecraft may have a very high Doppler dynamics and suffer from very weak signal conditions. Several questions naturally arise: i) What are the fundamental limits in terms of receiver dynamics and received signal conditions for SPP? ii) Can SPP and PPP techniques be used for space exploration? iii) What are the PPP fundamental operation limits?

This paper addresses these questions, and intends to complete the understanding of PPP from a signal processing standpoint, and provides the theoretical limits on the feasibility of SPP and PPP for space exploration. More specifically, the Cramér-Rao Bound (CRB), which gives the lower bound on the achievable estimation performance, is assessed both in terms of Doppler dynamics and signal-to-noise (SNR) ratio for the estimation of the time-delay, Doppler-shift and carrier phase.