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LUNAR FORMATION FLYING INVARIANT UNDER ZONAL HARMONIC PERTURBATIONS

Abstract

Formations flying of small satellites orbiting the Moon is currently considered a promising technology to provide communication and navigation services for both in-orbit and on-ground lunar activities. Their requirements set strict constraints on the altitude of the satellites, limiting it to medium and low lunar orbits, where the effects of perturbations associated to the non-uniform gravitational field of the Moon are not negligible. A major consequence of such perturbations is that any configuration designed based on the traditional Hill-Clohessy-Wiltshire model rapidly degrades, undermining the effectiveness of the formation or leading to potential collisions. To compensate for these effects, large reconfiguration maneuvers are necessary, but their extent is limited due to the little propellant budget characterizing small satellites. In this scenario, the design of formation configurations invariant under the zonal gravitational perturbation is of pivotal importance. We propose here a model that allows the compact characterization and simple design of relative trajectories for satellite formation flying that are invariant under zonal harmonic perturbations. The model is developed using a Hamiltonian formulation which includes all the zonal coefficients up to the desired degree. Canonical transformations are implemented to absorb the first order terms in the perturbation and rearrange the Hamiltonian function of the linear problem as the sum of three terms, one associated to the saddle equilibrium and two associated to harmonic oscillators. In this new form, the drift rate and the amplitude of in-track and cross-track oscillations of the relative trajectories are fully characterized by only 4 parameters, that can be easily converted into position and velocity coordinates for the satellites of the formation. Compared to other solutions in the literature, the model proposed here does not require any truncation of the zonal harmonic terms or numerical refinement to provide initial states associated to Jn-invariant trajectories with desired geometric properties. The effectiveness of the model is verified by means of numerical analysis using the high-fidelity LP-165 orbit propagator integrated in the General Mission Analysis Tool by NASA, considering different lunar orbits and focusing on bounded relative trajectories. The analysis results in a negligible drift and a variation in the amplitude of the oscillations below 1% of their initial value over 1 month.