Paper ID: 66394
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Orbital Dynamics (2) (7)

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KEPLERIAN MAP THEORY FOR HIGH-FIDELITY PREDICTION OF THE THIRD-BODY PERTURBATIVE EFFECT

Abstract

The Keplerian map was introduced to apply the perturbative approach to the circular restricted three-body problem, in case of small mass-ratio binary systems. The application of the model has been reduced to a narrow range of scenarios, since the accuracy appears to strongly depend on the distance of the third mass from the disturbing body.

This paper aims at enhancing the potentiality of the theory. The proposed model is a Lagrange planetary equations-based perturbative approach applied to the restricted three-body dynamical regime. Since only conservative forces are involved, the disturbing potential is derived as the scalar function, whose gradient equals the differential acceleration with respect to the reference Keplerian motion. This reference dynamical model assumes the body of negligible mass moving under the gravitational field exerted only by the primary body, considered in the centre-of-mass of the three-body system. This proposed approach avoids any assumptions on the mass-ratio of the binary system and accounts for the eccentric motion of the secondary body. The perturbing term is differentiated with respect to the Keplerian elements. In this context, it is demonstrated the need of using time, and not anomaly, as independent variable, coherently with the Lagrangian brackets derivation; the resulting additional terms, obtained through derivative chain rule, according to the non-linear relation true anomaly – time, leads to major improvements on the model accuracy. This study examines both numerical and Picard iteration-based semi-analytical approaches. To pursue long-term propagations, in this second scenario the perturbed period equation is derived, according to the discrete nature of the semi-analytical formulation.

A first analysis on the accuracy and computational efficiency involves 200 propagations of near-Earth asteroid 2010 JL88 orbital elements, characterised by high uncertainty. The percentage relative error, with respect to the integration of Newton's laws, is monitored, as well as the whole time needed for the simulations. The error keeps below 8.5% and 0.011% for the semi-analytical and numerical Keplerian map, respectively; furthermore, the numerical approach is able to reduce the computational time by almost 20% compared to Newton's equations. The accuracy of the model is further tested in the many-body scenario, propagating the orbital elements of the JUICE spacecraft; the resulting profiles overlap the available ephemerides.

A mission design based on the Keplerian map is eventually proposed. Since the Jovian system is the most gravitationally disturbed environment, the paper proposes an example of multi-flyby trajectory optimisation in the Jupiter sphere of influence.