Paper ID: 73489
oral
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Orbital Dynamics (1) (8)

Author: Mr. Alessandro Masat
Politecnico di Milano, Italy

Dr. Camilla Colombo
Politecnico di Milano, Italy
Dr. Arnaud Boutonnet
European Space Agency (ESA), Germany

ECCENTRIC ANOMALY SYNCHRONISM AND REGULARISED DYNAMICS FOR CONTINUUM INTERPLANETARY ORBITAL UNCERTAINTY PROPAGATION

Abstract

Several space applications involve quantifying the effects of uncertainty on space missions. For trajectory design, simulating the evolution of uncertain conditions in the spacecraft orbit is crucial to assess safety and robustness of a mission solution. Planetary protection compliance verification is such an example, where disposed human-made objects of interplanetary and Libration point missions undergo a completely uncontrolled dynamics, after being injected in graveyard orbits or due to injection errors and failures. Typical accuracy requirements demand the use of high-fidelity models, reason why most analyses have so far remained limited to the Cartesian formulation of the n-body dynamics. However, the nonlinearity of the equations of motion carries a computational burden increase, although the most subtle aspect is the definition of the independent integration variable: time. While time-varying dynamical phenomena are easy to interpret, this may not be the best choice from a computational viewpoint: without considering general relativity, autonomous systems (as orbital dynamics is, in classical physics) do not explicitly depend on time. Consequently, the common time flow may not be the description that best captures their evolution. Regularised formulations propose an alternative framework to orbital dynamics. Previous research [1] confirmed the efficiency of the Kustaanheimo-Stiefel (KS) formulation for high fidelity propagations, studying the planetary protection compliance of Solar Orbiter's launcher upper stage disposal manoeuvre. In the Keplerian case, KS equations of motion are linear, with the independent variable following the evolution of the eccentric anomaly. The system description is Lyapunov-stable for bound trajectories, in opposition to the usual time case. This work exploits the stability of the KS formulation to propagate the uncertainty synchronizing on the eccentric anomaly, tracking the physical time evolution as an additional joint state variable. The orbital uncertainty is treated as a single statistical quantity, rather than independent sampled states. The fictitious integration time allows a stable and regular description of the uncertainty evolution, also improving the understanding of flyby's scattering effect in interplanetary motion, because of the explicitly exponential KS dynamics. Similarly to [1], the simulation computational cost is almost halved. Simple fitting over the time element suffices to reconstruct the conventional definition of propagated uncertainty over the whole domain. Planetary protection and defence test cases are presented, analysing close approaches of human-made disposal objects and near-Earth asteroids.

[1] Masat, A., and Romano, M., and Colombo, C. "Kustaanheimo-Stiefel variables for Planetary Protection Compliance Analysis", Journal of Guidance, Control and Dynamics, 2022, accepted for publication.