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FAST CHAOS EXPANSIONS OF DIFFUSIVE AND SUB-DIFFUSIVE PROCESSES IN ORBITAL MECHANICS

Abstract

In this work, we propose to study diffusive and sub-diffusive processes in orbital mechanics with a novel methodology based on fast dynamic Polynomial Chaos Expansions (fdPCE). We will consider orbital mechanics nearly-integrable systems characterised by a stochastic perturbation. The quasi integrability allows one to expand the dynamics in a suitable set of basis functions and transcribe the original system of nonlinear differential equations into a system of linear or quasi-linear equations. Once the dynamics is transcribed we apply a variant of Polynomial Chaos Expansions (PCE), in which time is divided into segments and PCE are dynamically restarted over each segment. The combination of the two techniques leads to a scalable and efficient method to propagate probability distributions in stochastic, non-linear dynamical systems.

In the paper we will focus on diffusive and sub-diffusive processes coming from an uncertainty in the dynamic model or a dynamics subject to a stochastic perturbation. It will be shown how such stochastic perturbations are both due to noise-driven transport in regular regions and to transport by slow deformation of chaotic regions. In orbital mechanics, this is particularly relevant in order to study collisions between spacecraft in Low Earth Orbit, asteroid impact scenarios and other kinds of anomalies.

We will consider perturbations that can be modelled by different types of random-walks. We will show how the propagation of the probability distribution of the realisations of the dynamics induced by the perturbation can provide insights in the stochastic stability of the system or the rate at which it is diffusing. The novel formulation of PCE will allow us to account for epistemic uncertainties on the nature of the random-walk, deriving results that are valid for families of probability distributions.

Finally, we will present how to apply a control action in combination to fdPCE to manage the degree of diffusivity in the dynamics and, more in general, to achieve the desired terminal states under uncertainty.