Paper ID: 35132
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ASTRODYNAMICS SYMPOSIUM (C1)
Interactive Presentations (IP)

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A HIGH-ORDER IMPACT PROBABILITY COMPUTATION TOOL FOR EARTH-RESONANT RETURNS OF NEAR-EARTH OBJECTS

Abstract

Nonlinear propagation of uncertainties plays a key role in celestial mechanics. Orbit determination is affected by measurement errors; consequently, the knowledge of the state of spacecraft or celestial bodies is characterized by uncertainty, and the size of the uncertainty set rapidly increases along the trajectories due to nonlinearities.

Uncertainty propagation and estimation in nonlinear systems is extremely difficult. Present-day approaches mainly refer to linearized propagation models or full nonlinear Monte Carlo simulations. The tools used for the robust detection and prediction of planetary encounters and potential impacts of Near Earth Objects (NEO) are based on these techniques. Alternative methods based on the use of differential algebra were already presented by the authors. Differential algebra supplies the tools to compute the derivatives of functions within a computer environment. Consequently, the Taylor expansion of the flow of ordinary differential equations can be obtained by carrying out all the operations of any explicit integration scheme in the DA framework.

DA has already proven its efficiency in the non-linear propagation of uncertainties within different dynamical models. Nonetheless, the accuracy of the method drastically decreases in highly nonlinear dynamics. Examples of this kind can be found in the propagation of asteroids motion after a close encounter with a major body, as in the case of Apophis, with a close encounter in 2029 and a possible resonant return in 2036.

This paper introduces the concept of Automatic Domain Splitting to overcome the described issues and applies it to the problem of uncertainty propagation of NEO motion and the computation of the impact probability of resonant returns. During the integration of the initial conditions, the polynomial representing the current state is monitored. When the nonlinearities cause the high order terms of the polynomial to grow, integration is paused and the current domain is split along one variable. A maximum number of splits is imposed, and the final result is a set of polynomials, each describing a portion of the initial uncertainty domain.

Potentially hazardous subdomains (PHS) are then automatically identified. The impact probability is evaluated by integrating the probability density function over all the PHS. The asteroid (99942) Apophis is used as test case: its equinoctial parameters on 18th of June 2009, as retrieved from the Near Earth Object Dynamics Site in September 2009, are set as initial conditions; the developed algorithm is used to assess the impact probability of Apophis at its resonant return in 2036.