AN IMPROVED METHOD FOR ASTEROID IMPACT PROBABILITY DUE TO SWARM INTELLIGENCE ALGORITHMS

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ABSTRACT

Given the vast number of asteroids and comets in the Solar System, there is a self-preservation imperative to be vigilant about discovering and tracking asteroids and comets and determining whether or not they are on an Earth-impacting trajectory. This research aims to answer a fundamental question regarding potentially hazardous objects (PHOs): given the best orbit determination solution, i.e. a state and uncertainty at a specific time, what is the closest that asteroid ever gets to the Earth when propagated forwards in time? Another key question is: how can the computationally expensive process of running a Monte Carlo simulation, with potentially thousands or millions of samples, be improved? This paper introduces an improved method for the determination of Earth close approach minimum distances of potentially hazardous asteroids and comets. Compared to the current state of the art, the introduced method outperforms existing methods both in computational efficiency and effectiveness at finding virtual impactors (VI) that are not detected with traditional statistical methods, e.g., via a Monte Carlo simulation. Inspired by recent advancements in swarm intelligence (SI), this novel method characterizes the set of possible perigees and finds the minimum Earth close approach distance by posing the asteroid close approach problem as a trajectory optimization problem, wherein a modified Particle Swarm Optimization (PSO) implementation is used to find the smallest possible perigee for the VI given its best known (mean) orbit and the 3-sigma uncertainty bounds for all its orbital elements. Belonging to the class of swarm intelligence, PSO is a numerical optimization method inspired by the collective behavior of a flock of birds, school of fish, swarm of insects, or other creatures in search of food or escape from predators. With this new method, the classic Monte Carlo algorithm can be reframed as a "zeroth-order" swarm intelligence algorithm. Given a swarm's ability to share information between particles and move closer to the objective from one iteration to the next, improvement upon traditional methods is guaranteed. This paper focuses on the orbital dynamics of potentially hazardous objects, including a framework for the gravitational equations of motion in two propagation segments: first, a Sun-centered dynamics model where the PHO is in a closed, elliptical orbit, and second, an Earth-centered dynamics model (including the J2 perturbation due to the Earth's oblateness), where the PHO is on an open, hyperbolic trajectory. Ephemerides from the NASA JPL NAIF SPICE Toolkit are used to compute third-body perturbations due to the 8 major planets and Pluto, Ceres, Pallas, and Vesta and the PHO-Earth close approach distance. The novel method is applied in case studies on notable PHOs, including the asteroids Apophis and Bennu. The presented method contributes to the global planetary defense effort by accurately predicting the "worst-case scenario" Earth close approach for a given potentially hazardous object and can be applied to

other problems that are currently analyzed via statistical methods but would be better posed as optimization problems.

Comments:

-Topic: NEO Characterization

-Oral presentation

-Eligible for the student competition

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