Topic: Space Mission & Campaign Design

OPTIMAL IMPULSIVE/LOW-THRUST TRAJECTORIES FOR ASTEROID DEFLECTION VIA KINETIC IMPACT

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ABSTRACT

This work considers the trajectory optimization of a kinetic impactor spacecraft, which is sent to collide with a threatening near-Earth asteroid. As a result of the impact, the subsequent path of the asteroid is very modestly changed. The goal is to maximize the perigee radius of the deflected asteroid (in this instance Apophis) at its closest approach to Earth, with the important variables such as the date of Earth departure, the direction of the departure, the thrust program for the low-thrust motor, and the date of the collision all being optimization parameters. The mission is assumed to be qualitatively similar to that of the DART mission; it departs Earth on a local hyperbolic trajectory and then uses low-thrust electric propulsion for the heliocentric phase until impact. High fidelity is achieved by using the SPICE ephemeris for the motion of the asteroid target, the motion of the Earth, and the positions of the planets as needed to determine their perturbing effects on the spacecraft trajectory. To avoid a loss in accuracy of the amount of deflection obtained, at the time of close approach to Earth the deflection is obtained by using the system state transition matrix and the small, known change in the velocity of the asteroid as a result of the earlier impact.

The problem is solved using Particle Swarm Optimization (PSO), a swarm intelligence method that requires that the optimization be transcribed into a parameter optimization problem with a modest number (i.e. 10's) of free parameters. This is accomplished in part by assuming *a priori* that the programs for the history of the in-plane and out-of-plane thrust pointing angles can be represented by 5th degree polynomials in (flight) time. Since the PSO has no native method for incorporating equality constraints the constraint that enforces interception, i.e. impact, is included as a penalty function in the objective. The PSO solution, which is necessarily sub-optimal because of the assumed form for the thrust pointing histories, has in a few cases been confirmed using a separate numerical optimization approach. In this "direct" solution the continuous optimal control problem is transcribed into a nonlinear programming (NLP) problem, now using many 100's of NLP parameters, and the equations of motion become nonlinear equality constraints. This

transcription required the development of a Runge-Kutta (RK) parallel-shooting code, implemented in MATLAB for the first time. When the PSO solution is used as the required initial guess for the NLP problem the results are virtually the same, showing that the “true” optimal thrust pointing is in fact well approximated by the smooth 5th degree polynomials assumed.