Paper ID: 82288
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22nd IAA SYMPOSIUM ON SPACE DEBRIS (A6)
Operations in Space Debris Environment, Situational Awareness - SSA (7)

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COLLISION AVOIDANCE MANEUVER DESIGN BY A FAST RECURSIVE POLYNOMIAL FORMULATION

Abstract

Ensuring safety for spacecraft operations has become a paramount concern due to the proliferation of space debris and the saturation of valuable orbital regimes. In this regard, collision avoidance maneuvers (CAMs) have emerged as critical requirements for spacecraft operators, aiming to efficiently navigate through potentially hazardous encounters. Given the forecasted increasing frequency of conjunctions, the autonomous computation of fuel-efficient CAMs is crucial to reducing costs and improving the performance of future operations.

We propose a simple and reliable algorithm for CAMs, capable of computing impulsive, multi-impulsive, and low-thrust maneuvers. Utilizing differential algebra (DA), safety metrics, e.g., the probability of collision (PoC), are approximated by a polynomial of arbitrary order as a function of the control. The method initiates by computing the CAM via a first-order greedy optimization approach, wherein the control action is applied in the direction of the gradient of the chosen safety metric to maximize its change. For instance, in the case of a single impulsive Delta-V and PoC, the first-order greedy solution is:

$$\Delta v = \frac{PoC_{obj} - P\bar{o}C}{||\vec{\nabla} PoC||^2} \vec{\nabla} PoC, \tag{1}$$

where PoC_{obj} is the objective PoC, $P\bar{o}C$ is the PoC of the ballistic trajectory, and $\vec{\nabla} PoC$ is its gradient w.r.t. the decision variables. This approach is generalized to higher polynomial orders using a recursive method: an n-th order generalized gradient is defined using the solution of the (n-1)-th order polynomial, reducing the problem to a new linear system to solve recursively until convergence is reached. This enables achieving high accuracy solutions even for highly nonlinear safety metrics and dynamics.

Since most of the operations involved are polynomial evaluations, the method is computationally efficient, with run times typically between 0.1 s and 1 s. Moreover, no restrictions on the considered dynamics are necessary; thus, any Earth orbital regimes (LEO, GEO, GTO, etc.) and even Cislunar orbits can be handled. In the latter case, the Cauchy-Green tensor can be used to extract additional metrics to minimize the impact of the maneuver on post-conjunction dynamics.