COLLISION AVOIDANCE FOR SHORT-TERM SPACE ENCOUNTERS USING THE SCENARIO APPROACH

Romain Serra(1), **Denis Arzelier**(2), **and Aude Rondepierre**(3)
(1,2)*CNRS, LAAS, Univ de Toulouse, 7 avenue du Colonel Roche F-31400 Toulouse, France.*
+33561336327, serra@laas.fr, arzelier@laas.fr
(1,3)*INSA, Univ de Toulouse, 135 avenue de Rangueil F-31400 Toulouse, France.*
(3)*IMT, Univ de Toulouse, 118 route de Narbonne F-31062 Toulouse, France.*
aude.rondepierre@math.univ-toulouse.fr

Abstract:

The ever-growing population of space debris has become a constant threat for Earth satellites. On-ground tracking radars allow to foresee potential collisions and consequent alerts are sent to operators several days before a would-be conjunction of a debris with one of the spacecraft they monitor. These messages describe the geometry as well as position and velocity at some reference time of a pair of potentially colliding objects. Because of the uncertain nature of the data, the risk is computed via a probabilistic metric. When the collision probability is too high compared to the safety threshold, the operator would then need to perform an evasive maneuver. The design of such an operation is driven by fuel-consumption in order to have the slightest impact on mission lifetime. Assuming that statistical information is available for characterizing uncertainty, an intuitive formulation of the problem belongs to the class of chance-constrained optimization problems where at least one constraint is probabilistic [1], [2], [3]. Since chance-constrained problems are generally hard to solve, simplifying assumptions are usually made in the literature to obtain practical results, for instance by reducing the dimension of the optimization space [4, 5] or even avoiding the probabilistic formulation [6, 7]. In the present paper, no relaxation is done concerning the optimization vector and the probabilistic formulation is dealt with indirectly.

This study focuses on the design of a single maneuver to be executed at a fixed time before conjunction. Assuming high-thrust chemical propulsion, an impulsive idealization of the finite powered control is considered. In practice, this kind of space operation is usually effective enough to reduce the risk to an acceptable level. The conjunction is assumed to be a short-term encounter involving two spherical objects [8, 9]. The short-term model describes conjunctions with high relative speeds at stake that typically occur in Low Earth Orbit (LEO). It gives birth to the notion of tube of collision that is exploited here to put the problem into equations. As in [4], the effects of the maneuver are computed assuming Keplerian dynamics. Consequently, orbit propagation may be done analytically thanks to the Lagrange coefficients f and g [10, 11, 12]. The original chance-constrained problem is handled via the so-called scenario approach [13, 14]. Using this method, admissible solutions of the genuine probabilistic optimization problem are provided with some predefined confidence level when a convexity property of the realizable set is verified [14]. Unfortunately, this is not the case for the problem of collision avoidance tackled in this paper. Still, the scenario approach offers a practical and useful way for designing fuel-efficient maneuvers. This is demonstrated by the results obtained in the proposed numerical example. The test case originates from a real collision alert sent by the Joint Space Operation Center (JSpOC) to our industrial partner Airbus Defence and Space (ADS) for a satellite on a circular orbit. A comparison to a line search in a heuristic direction - as in [5] - shows the efficiency of the scenario approach.

Keywords: *Collision Avoidance, Space Debris, Short-term Encounter, Tube of Collision, Chance-constrained Optimization, Scenario Approach, Lagrange Coefficients.*

1. References

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