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OPTIMAL INTERCEPTION OF OPTIMALLY EVASIVE SPACECRAFT

Abstract

A flight path optimization problem can be modeled as a one-sided optimization problem (the classical optimal control problem) or a two-sided optimization problem. The one-sided optimization problem considers only a single dynamical system and consists in minimizing a given objective function while simultaneously satisfying some boundary conditions. In this research, the problem of the optimal (three-dimensional) interception of an optimally evasive spacecraft by a pursuing spacecraft is addressed. The time for interception is to be minimized by the pursuing spacecraft and maximized by the evading spacecraft. This problem involves two competing players and is best modeled as a two-sided optimization problem, i.e. it becomes a zero-sum, two-player differential game. Zero-sum games were first introduced by Isaacs and are also referred to as "pursuit-evasion games". In the context of zero-sum games, the optimal trajectories of the two spacecraft correspond to a so-called "saddle point equilibrium solution" of the game. The related necessary conditions are relatively straightforward to derive and can be viewed as an extension of the necessary conditions for optimality that hold in optimal control theory. Only a few problem with simplified dynamics are amenable to an analytical solution. For problems with realistic dynamics the only choice is numerical solution. This work presents a recently developed method, termed "semi-direct collocation with nonlinear programming", devoted to the numerical solution of dynamic games. This method is based on the formal conversion of the two-sided optimization problem into a single-objective one, by employing the analytical necessary conditions for optimality related to one of the two players. This fact implies that the adjoint variables of one of the two spacecraft are directly involved in the optimization process, which needs a reasonable guess to yield an accurate saddle point equilibrium solution. The trial-and-error selection of first attempt values for the (non-intuitive) adjoint variables is very challenging for the problem at hand. In this work, an approximate, first attempt solution is provided through the use of a genetic algorithm in the preprocessing phase. Three qualitatively different cases are considered. In the first example the pursuer and the evader are represented by two spacecraft orbiting Earth in two distinct orbits (at the initial time). The second and third case involve two missiles, and a missile that pursues an orbiting spacecraft, respectively. In all cases the semi-direct collocation with nonlinear programming algorithm successfully finds the saddle point trajectories of both players, thus proving its effectiveness and robustness