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OPTIMIZATION OF LOW THRUST ORBITAL TRANSFER USING THE EVOLUTION STRATEGIES WITH COVARIANCE MATRIX ADAPTATION

Abstract

The problem of low thrust orbital transfer between non-coplanar orbits is considered. The optimization criterion is considered as minimum transfer time or minimum fuel. The optimal control problem is reduced to the boundary value problem for the system of ordinary differential equations with the use of the maximum principle. The boundary value problem is reduced to the system of nonlinear equations where the unknowns are the values of the adjoint variables at the start of the trajectory. The solutions of this system of nonlinear equations are very sensitive to small changes in the values of adjoint variables.The application of different types of Quasi-Newton method is not effective for solving the problem because the convergence radius is very small and it is impossible to explore the problem randomly to find the good initial guess. Many researchers proposed to use different types of continuation or homotopy methods in order to cope with the problem of the initial guess. There is no doubt that these methods are reliable. But it is very difficult to find the continuation path, especially when the optimal control structure is discontinuous with a large number of thrust arcs. In this paper we propose to use the method of evolution strategies with covariance matrix adaptation in order to avoid difficulties mentioned above. The minimization criterion is introduced as the sum of consumption index (e.g. the fuel consumption required for the transfer) with the respective scale and the sum of squares of boundary conditions' residuals. The respective scale monotonously decreases down to zero during the iterative search within the evolutionary strategy. This kind of algorithm enables us to expect that at the initial stage of the research we can find the vicinity of the global optimum and at the final stage we can find the global optimum itself (the boundary value problem solution). At the final stage of the research the considered minimization criterion should become zero. The proposed method is proved to be effective and allows fulfilling a large numerical analysis which is required to obtain the optimal control structure and the characteristics of optimal trajectory without averaging on angular variable. The numerical results for several orbital transfer problems and their comparison with the results which were received by other authors are presented in order to describe the effectiveness and verification of the proposed method. The numerical results for the analysis of different types of extremals are also presented.