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MAXIMUM-LIKELIHOOD ESTIMATION OPTIMIZER FOR CONSTRAINED, TIME-OPTIMAL SATELLITE REORIENTATION

Abstract

Time-optimal satellite reorientation maneuvers are difficult to compute, even with direct methods of optimal control. This paper examines the use of the Covariance Matrix Adaptation-Evolution Strategy (Ref. 1) as part of a hybrid method to generate optimal controls for such problems. The example case used is similar to the Swift gamma-ray burst detector satellite, which must slew to acquire new astronomical targets before the visible and x-ray emissions fade; the instruments must remain active and the slew path must avoid transiting the solar, terrestrial or lunar disks so that the visible and x-ray sensors are not damaged.

Previous work (Ref. 2) has shown that heuristic methods such as Particle Swarm Optimization (PSO) and Bacteria Foraging Optimization (BFO) can provide good estimates for use in a pseudospectral (PS) algorithm, forming a two-stage, hybrid method. In this paper, CMA-ES is shown to provide a much higher quality estimate of the control solution for a problem that includes multiple path constraints. The CMA-ES algorithm offers two significant advantages over PSO or BFO: it builds an approximation to the covariance matrix for the probability distribution of optima in the search space, and uses that to determine a direction of maximum likelihood for the search, reducing the chance of stagnation; and, in analogy with the variable-metric Davidon-Fletcher-Powell method, it treats the covariance matrix as the inverse Hessian, resulting in a quasi-Newton method with superior convergence properties. The result is that the combination of CMA-ES and the PS methods can generate a highly accurate solution in approximately half the time required by the combination of PSO and PS methods. Indeed, further reduction in computation time may permit the CMA-ES algorithm to be employed by itself in the problem solution. The paper will also discuss alternative formulations for modeling the control torques that could make this possible.

1. Hansen, N., Niederberger, S., Guzzella, L., Koumoutsakos, P., "A method for handling uncertainty in evolutionary optimization with an application in feedback control of combustion," IEEE Transactions in Evolutionary Computation, 2009.

2. Melton, R.G., "Hybrid Methods for Determining Time-Optimal, Constrained Spacecraft Reorientation Maneuvers," Advances in the Astronautical Sciences, Univelt, Inc., Vol. 145, pp. 749-762, 2012.