Tuning Monotonic Basin Hopping: Improving the Efficiency of Stochastic Search as Applied to Low-Thrust Trajectory Optimization

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ABSTRACT

The optimization of low-thrust interplanetary trajectories is a highly complex task. Such design problems are characterized by hundreds to thousands of decision variables and tens to hundreds of constraints. Many locally optimal solutions often exist. These problems are often solved using a nonlinear programming (NLP) problem solver but all such solvers require a good initial guess. Historically initial guesses are generated by intuition or by solving a reduced-fidelity version of the problem, such as by approximating a low-thrust orbit transfer as a Lambert arc. This can result in a great deal of hands-on work and one can still miss the globally optimal solution if it is non-intuitive.

Several researchers have sought alternative ways to generate initial guesses for low-thrust trajectory design problems using a stochastic search method called monotonic basin hopping (MBH) [1]. MBH is a hybrid of the classic multi-start algorithm, an NLP solver, and a stochastic search step. First a random point is chosen in the decision space and the NLP solver is run from that point to attempt to find a feasible solution. This step is repeated until a feasible solution is found. MBH then attempts to improve upon the current solution by "hopping," i.e. adding small random perturbations to the decision vector and re-optimizing using the NLP solver. Over many iterations, MBH progresses towards a better solution.

This paper will address one specific component of MBH – the probability distribution from which the random "hop" is drawn. In the classical MBH, the hop is drawn from a uniform ball of some user-defined radius surrounding the current best point. The choice of radius for the ball defines the balance between exploration of the search space and exploitation of the local area around the current solution. However this may not be the most efficient search. In nature, animals foraging for food tend to take many short search steps punctuated by a few very large ones, defining a probability distribution with a narrow central peak and long tails. This observation inspired Englander, Conway, and Williams [2] to test a modified version of MBH which drew hops from a Cauchy distribution. The modified MBH seemed to perform at least as well as the classical version but no thorough testing was performed. In this paper the Cauchy version of MBH, as well as several other variants, will be thoroughly benchmarked against the classical MBH on problems of interest to the astrodynamics community.

[1] *Vasile, M., Minisci, E. and Locatelli, M., "Analysis of Some Global Optimization Algorithms for Space Trajectory Design," AIAA Journal of Spacecraft and Rockets, 2010, Vol. 47, No. 2, pp. 334-344.*
[2] *Englander, J. A., Conway, B. A., and Williams, T., "Automated Interplanetary Mission Planning," AAS/AIAA Astrodynamics Specialist Conference, Minneapolis, MN, August 2012.*