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N-BODY BOUNDARY VALUE PROBLEM SOLVER USING MONOTONIC BASIN HOPPING WITH APPLICATIONS TO EARTH-MOON TRANSFER

Abstract

The two-point boundary value problem in classical orbital mechanics, also known as the Lambert problem, is confined to a two body system. However it is also necessary sometimes in the n-body system to find the trajectory that reaches a final state from a given initial position, e.g. in the Earth-Moon system where a two-body approximation is insufficient. We introduce a numerical solver capable of solving boundary problems with the presence of multiple bodies. The program is written in C++ and searches for solutions with the monotonic basin hopping algorithm.

The program uses the analytical solution of the Lambert's problem as initial guess, with the central body chosen to be the one exerting the most gravitational force on the spacecraft. A built-in high speed and high precision numerical integrator then finds the final state given the initial state and flight time. The monotonic basin hopping algorithm with a sequential quadratic programming (SQP) local optimizer is used to search for solutions in the space of input parameters, which is both efficient and less sensitive to initial guess, so that there is a much higher chance to find the global optimal solution instead of being trapped locally.

In the case that a solution cannot be found, the program turns down the gravity of all but the central body and then turn them back up gradually, using the continuation method to ensure a smooth transition from the initial guess to the solution. The program is also being developed so that not only ballistic but also low-thrust trajectories can be considered.

We demonstrate the applications of this program to missions such as the JAXA EQUULEUS, in which a CubeSat uses the moon for gravity assist. For this satellite to transfer into the Earth-Moon-Halo orbit, it burns at a known initial position closer to the Earth, then enters a transfer orbit and eventually reaches a given final state near the Moon. It is therefore necessary to solve the 3-body boundary problem to find such trajectories and connect the discontinuity. Preliminary tests show that for arbitrary discontinuities on the Earth-Moon transfer orbit, a solution can usually be found by the program within a few minutes without the user's intervention. Our tool can significantly speed up the matching process of low-energy flybys at the Moon and other celestial bodies. It can serve as an extension of the classical Lambert problem with a wider range of applicability.