Multi-Objective PSO for Interplanetary Trajectory Design

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ABSTRACT
The paper proposes the application of the PSO technique, to solve the optimal control problem for interplanetary trajectories design. A constrained bi-objective optimization scheme is proposed to minimize both the propellant mass to maneuver and the transfer time from the Earth to the target planet, while respecting the celestial mechanics.

Categories and Subject Descriptors
I.6.3 [**Simulation and modeling**]: applications

General Terms
Algorithms, Design.

Keywords
Interplanetary transfers, Trajectory design, Astrodynamics.

1. INTRODUCTION TO THE PROBLEM
To bring a spacecraft from the Earth to its final orbit in space asks to solve a control problem on the vehicle trajectory, constrained by the celestial mechanics of the probe, the departing body and the arrival planet. Because of the propulsion units technological limitations the trajectory control can be obtained by low efficiency maneuvers accomplished with high accelerations shortly applied or thanks to a very small acceleration maintained over a long time span. To improve the interplanetary trajectory control the Gravity Assist (GA) maneuver is typically exploited: GA is a technique - well-known in the celestial mechanics community- that benefits of the spacecraft gravitational interaction with massive planets to further change the dynamics of the vehicle: by passing nearby a planet the probe's velocity vector changes with no fuel expense. Therefore, to design a spacecraft trajectory, constrained in terms of initial and final position in space, firstly the propulsion class – either high or low thrust- must be selected; depending on the selected propulsion unit the thrust profile must be defined; no matter of the type of selected propulsion the launch date, the transfer time, the number of GA maneuvers, the planet to be exploited for GA must be selected. A typical criterion for those control variable selection is the propellant mass minimization, while containing the time to transfer from the Earth to the target planet. Therefore, the design problem is defined on a mixed search space, both discrete – the number and type of planets for GA- and continuous – the time and accelerations profiles. It is worth to underline that the propellant mass consumption in terms of the former variables is a multimodal function even discontinuous in some areas. As a consequence, to manage the whole search space by means of optimization, necessarily asks for a global optimizer, not gradient-based. The current work successfully selected the PSO – tailored to manage multi-objective optimization (MOPSO) – to design the control profile of interplanetary trajectories keeping free the largest number of involved parameters.

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2. THE MOPSO TAILORING
The basic scheme of PSO has been slightly revisited to face with multi-objective optimization [1]. The set of optimal solutions is defined according to the dominance concept and the Pareto front is looked for. In particular, the global best particle each particle in the swarm is partially attracted by, may vary depending on the particle the velocity is currently computed for. An archive of leader particles is refilled- at each step - by applying the algorithm suggested in [2]; a tournament selection is run for each particle to select the global best to be used for the velocity computation. The former strategy keeps the swarm well-spread on the quite wide search space. To further avoid niching, mutation is also applied randomly to 10% of the swarm to change one of the variable vector components. The *self* and *swarm confidence* coefficients have been settled to 1.4 and 1.8 respectively, while the *inertia factor* varies linearly during the run from in the [0.5 1] interval. A dedicated architecture based on the sequential and in-parallel combination of multiple MOPSO optimizers have been designed to speed up the run and enhance the Pareto Front detection.

3. RESULTS
The MOPSO application to different scenarios focused on the optimization of space probes trajectories revealed to be quite effective no matter of the control strategy selected. A quick but precise pruning of the wide search space is fundamental in mission analysis to identify the areas of minima location within a further local optimization will be run to refine the solution.

4. REFERENCES
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