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Interplanetary low-thrust trajectories optimization using deterministic and stochastic methods

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The patched-conic method [2] is fundamental importance in the calculation of interplanetary orbits in astrodynamics, performing an approach to the orbital dynamics of a spacecraft. This method uses the gravitational attraction of the most significant celestial body at any given time as a central field force, and with that, the spacecraft describes a Keplerian trajectory immersed in a sphere of influence around that body. With that, the set of these trajectories form the studied maneuver.

In this paper, it is studied the problem of launching a spacecraft from a nominal earth orbit with the objective of arriving deep space, using multiple swing-by maneuvers in a low-thrust trajectory (Figure 1 shows an example of this maneuver). The two-body problem and the patched-conics approach are used as the mathematical models. During the close approach to planets the patched-conic method will be implemented modeling the swing-by maneuver, otherwise the spacecraft will be in an elliptical orbit around the Sun.

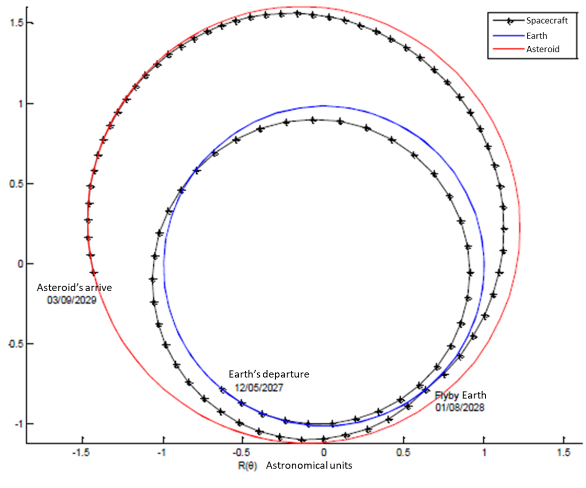

Figure 1: Example of a low-thrust interplanetary trajectory using gravity assisted maneuvers [4]

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It was used the formulation of powered three-dimensional swing-by. The powered swing-by maneuver combines the gravity of the celestial body with the application of an impulse in the periapsis of the orbit and in this case it was consider the non-planar maneuver. This gravity assisted maneuver can be modeled by equations (1) and (2).

$$sen(\delta) = \frac{1}{1 + \frac{r_p V_\infty^2}{\mu_2}} \tag{1}$$

$$\begin{aligned} \vec{V}_\infty^- = V_\infty^- \left(sen\delta\ cos\alpha\ cos\beta - cos\delta\ cos\alpha\ sen\beta\ sen\gamma - cos\delta\ sen\alpha\ cos\gamma\right) \hat{i} + \\ + V_\infty^- \left(sen\delta\ sen\alpha\ cos\beta - cos\delta\ sen\alpha\ sen\beta\ sen\gamma + cos\delta\ cos\alpha\ cos\gamma\right) \hat{j} + \\ + V_\infty^- \left(sen\delta\ sen\beta + cos\delta\ cos\beta\ sen\gamma\right) \hat{k} \end{aligned} \tag{2}$$

In the formulation some constants and variables thrust propulsion systems are modeled, like electric and nuclear propulsion. The objective of the work is, through optimization methods, to calculate trajectories that make the spacecraft spend the shortest possible time to reach its destination. It is expected to implement the structure of the algorithm to consider some perturbations with greater magnitude. Several different cases will be considered in the simulations, varying the celestial bodies to which the spacecraft is launched, thus creating a program that presents results for different missions.

Concerning the optimization methods, it will compare the results about genetic algorithm [3] with other methods like either a algorithm based in monotonic basin hopping that is a mixed deterministic/stochastic solver or some algorithm that uses the Sims-Flanagan transcription [1]. Finally a algorithm that uses a Biggs direct method [4] will implemented and the results will be compare.

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References

[1] Englander, J. A. and Conway, B. A. Automated solution of the low-thrust interplanetary trajectory problem, *AIAA Journal of Guidance, Control, and Dynamics*, volume 40, pages 15-27, 2017. DOI: 10.2514/1.G002124.

[2] Li, J., Zhao, J. and Li, F., A new method of patched-conic for interplanetary orbit, *Optik*, volume 156, pages 121-127, 2018. DOI: 10.1016/j.ijleo.2017.10.153.

[3] Neves, G. M., dos Santos, D. P., Domingos, R. C., and Formiga, J. K. Orbital maneuvers for asteroids using genetic algorithm, *J. Phys.: Conf. Ser.*, volume 1365, pages 012019, 2019. DOI: 10.1088/1742-6596/1365/1/012019.

[4] Santos, D. P. S. Otimização de Trajetórias Espaciais com Propulsão Elétrica Solar e Manobras Gravitacionalmente Assistidas, Tese de Doutorado, INPE, 2009.