Rendezvous missions with minimoons from L1

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We propose to present asteroid capture missions with the so-called minimoons. Minimoons are small asteroids that are temporarily captured objects on orbits in the Earth-Moon system. It has been suggested that, despite their small capture probability, at any time there are one or two meter diameter minimoons, and progressively greater numbers at smaller diameters. The minimoons orbits differ significantly from elliptical orbits which renders a rendezvous mission more challenging, however they offer many advantages for such missions that overcome this fact. First, they are already on geocentric orbits which results in short duration missions with low Delta-v, this translates in cost efficiency and low-risk targets. Second, beside their close proximity to Earth, an advantage is their small size since it provides us with the luxury to retrieve the entire asteroid and not only a sample of material. Accessing the interior structure of a near-Earth satellite in its morphological context is crucial to an in-depth analysis of the structure of the asteroid. Historically, 2006 RH120 is the only minimoon that has been detected but work is ongoing to determine which modifications to current observation facilities is necessary to provide detection algorithm capabilities. In the event that detection is successful, an efficient algorithm to produce a space mission to rendezvous with the detected minimoon is highly desirable to take advantage of this opportunity. This is the main focus of our work. For the design of the mission we propose the following. The spacecraft is first placed in hibernation on a Lissajoux orbit around the liberation point L1 of the Earth-Moon system. We focus on eight-shaped Lissajoux orbits to take advantage of the stability properties of their invariant manifolds for our transfers since the cost to minimize is the spacecraft fuel consumption. Once a minimoon has been detected we must choose a point on its orbit to rendezvous (in position and velocities) with the spacecraft. This is determined using a combination of distance between the minimoon's orbit to L1 and its energy level with respect to the Lissajoux orbit on which the spacecraft is hibernating. Once the spacecraft rendezvous with the minimoon, it will escort the temporarily captured object to analyze it until the withdrawal time when the spacecraft exits the orbit to return to its hibernating location awaiting for another minimoon to be detected. The entire mission including the return portion can be stated as an optimal control problem, however we choose to break it into smaller sub-problems as a first step to be refined later. To model our control system, we use the circular three-body problem since it provides a good approximation in the vicinity of the Earth-Moon dynamics. Expansion to more refined models will be considered once the problem has been solved for this first approximation. The problem is solved in several steps. First, we consider the time minimal problem since we will use a multiple of it for the minimal fuel consumption problem with fixed time. The techniques used to produce the transfers involve an indirect method based on the necessary optimality condition of the Pontriagyn maximum principle coupled with a continuation method to address the sensitivity of the numerical algorithm to initial values. Time local optimality is verified by computing the Jacobi fields of the Hamiltonian system associated to our optimal control problem to check the second-order conditions of optimality and determine the non-existence of conjugate points.

Acknowledgements: NSF Division of Mathematical Sciences award 1109937.

References: B. Bonnard, J.-B. Caillau and G. Picot, "Geometric and Numerical Techniques in Optimal Control of the Two and Three-Body Problems", Commun. Inf. Syst., 10 (2010), 239–278; M. Chyba, G. Patterson, G. Picot, M. Granvik, R. Jedicke, J. Vaubaillon, "Time-minimal orbital transfers to temporarily-captured natural Earth satellites", OCA5 — Advances in Optimization and Control with Applications Springer Proceedings in Mathematics, To Appear (2014); B. Bolin, Jedicke, R., Granvik, M., Wainscoat, R. J., Chyba, M., Vauballion, J., Brown, P., "Detecting Earth's Temporarily Captured Natural Satellites", (2014). Submitted to Icarus; M. Chyba, G. Patterson, G. Picot, M. Granvik, R. Jedicke, J. Vaubaillon (2014) "Designing Rendez-vous Missions with Mini-Moons using Geometric Optimal Control", Special issue of the AIMS Journal of Industrial and Management Optimization, Vol 10(2), pp 477–501; M. Granvik, R. Jedicke, B. Bolin, M. Chyba, G. Patterson, G. Picot (2013) "Earth's Temporarily-Captured Natural Satellites — The First Step Towards Utilization of Asteroid Resources. Asteroids". Prospective Energy and Material Resources. Springer-Verlag, pp 151–167; M. Granvik, J. Vaubaillon, R. Jedicke, "The population of natural Earth satellites", Icarus, (2012), Vol. 218, 262-277.