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SIMPLE GRAVITATIONAL MODELS AND CONTROL LAWS FOR AUTONOMOUS OPERATIONS IN PROXIMITY OF UNIFORMLY ROTATING ASTEROIDS

Andrea Turconi[1], Phil Palmer[2], and Mark Roberts[3]
[1]*Surrey Space Centre, University of Surrey GU27XH Guildford UK, +447447875304,*
[1]*Surrey Space Centre, University of Surrey GU27XH Guildford UK,*
[3]*Mark Roberts, Department of Mathematics, University of Surrey GU27XH Guildford UK,*

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ABSTRACT

The concept of sending a fleet of survey spacecraft to characterise Potentially Hazardous Asteroids would be unsustainable when using the current operations approach. Maintaining missions in proximity of small bodies in fact requires extensive orbit determination campaigns and a ground-in-the-loop operations scenario. All the manoeuvres have to be carefully planned in advance thanks to a model of the gravitational potential which becomes more and more detailed along the mission.

Recent developments in on-board navigation paved the way for autonomous proximity operations. Thanks to systems like the OBIRON (On-board Image Registration and Optical Navigation) by JPL and the DSAC (Deep Space Atomic Clock) by NASA, future spacecraft will have, directly on-board, the knowledge of their relative position and velocity with respect to the asteroid. The missing part for enabling autonomous operations in the vicinity of asteroids is then a model of the irregular gravitational potential can be stored and used by the spacecraft to steer itself around the asteroid. Such a model shall be governed by a small number of parameters and at the same time represent well the key features of the dynamical environment about asteroids.
The state of the art gravitational models for bodies with irregular shapes are polyhedral models with thousands of faces and vertices and high-order spherical harmonics expansions. Given the limited computational power available, those models are too complex for an extensive use for on-board control.

In this paper we present a class of approximate gravitational models for asteroids in uniform rotation and an optimisation technique for their derivation from the main characteristics of the small bodies: total mass, rotation rate and shape.
The overall mass is available thanks to flybys performed at rendezvous, a phase when ground based operations will be anyway required. At that stage stereo imaging and the initialisation of the optical navigation software will also provide a shape model and the body rotation rate.
We show that the simple model derived from these data represents well the dynamical environment around the asteroid, in particular the position and Jacobi energy of the equilibrium points generated by the balance of gravity and centrifugal acceleration in the body fixed frame.

In the reference frame, fixed with an asteroid in uniform rotation, it exists a constant of motion: the Jacobi Energy Integral. As seen in the well known Circular Restricted Three Body Problem (CR3BP) at any given value of Jacobi Energy the so-called Zero-velocity Curves can be determined. Those curves enclose regions where the motion is not permitted for the given energy level.
Trajectories at energies whose Zero-velocity curves completely enclose the asteroid will be therefore stable against impact as shown in Figure 1

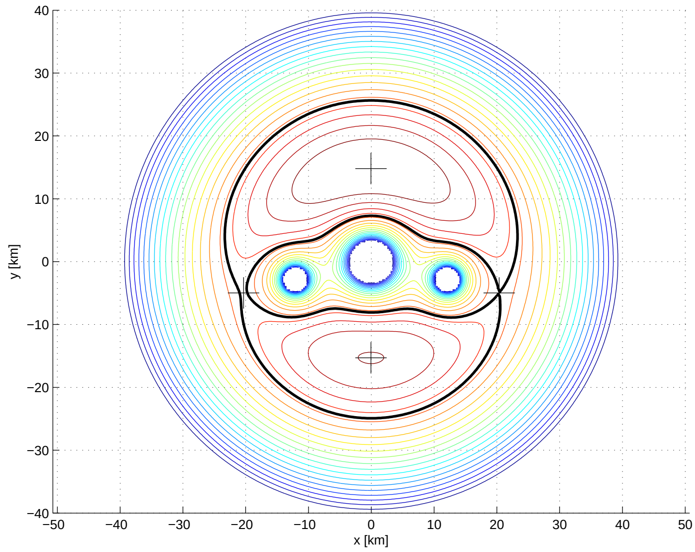

Figure 1 - Zero-velocity curves for the simple gravitational model of 433 Eros. The + marks identify the positions of the equilibrium points while the thick black line highlights the energy level of the lowest equilibrium point which gives also the energy limit for stability against impact.

Taking advantage of this properties we show control laws making use of the proposed approximate gravitational model for maintaining the spacecraft in a prograde orbit about the asteroid while ensuring that no impact will occur with the body.
When the rotational equilibrium points exist outside the body, with the same control law we can also steer the spacecraft towards one of them achieving a synchronous orbit about the asteroid. Preliminary results for this scenario are shown in Figure 2

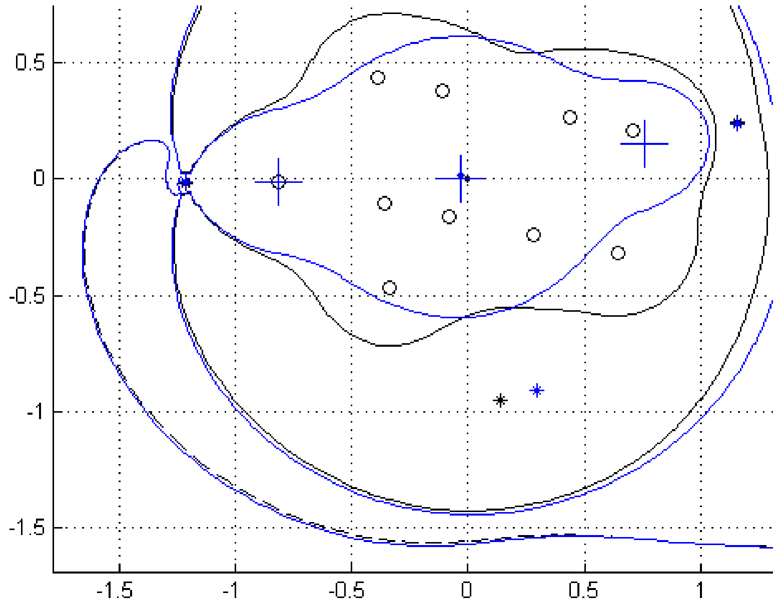

Figure 2 - Comparison between controlled trajectories targeting the lowest energy equilibrium point using the truth model (black and dashed line) and the approximate model (blue solid line)