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MODELLING SMALL BODIES GRAVITATIONAL POTENTIAL FOR AUTONOMOUS PROXIMITY OPERATIONS

Abstract

Maintaining missions in proximity of small bodies involves extensive orbit determination and ground station time due to the current ground-in-the-loop approach. The prospect of having multiple concurrent missions around different targets requires the development of concepts and capabilities for autonomous proximity operations. Advances in on-board optical navigation by landmark maps and on-board real-time radio navigation via deep space atomic clocks, will ensure on-board knowledge of relative distance and velocity with respect to the small body, paving the way for autonomous guidance at asteroids. The missing elements for achieving this goal are gravity models, simple enough to be easily used by the spacecraft to steer itself around the asteroid, and guidance laws that rely on such approximate models. In this paper, we identify a class of models that can represent some characteristics of the dynamical environment around small bodies with sufficient accuracy to enable autonomous guidance. We found that sets of three point masses are suitable to represent the rotational equilibrium points generated by the balance of gravity and centrifugal acceleration in the body-fixed frame. The equilibrium point at the lowest Jacobi energy can be viewed as the energy-gateway to the surface and information of the location and energy of this point can then be used by control laws to comply with a condition of stability against impact for orbital trajectories. We show an optimisation process for the derivation of three-point mass models from higher order ones and compare the profile of the Zero-Velocity curves between the two models. We define an autonomous guidance law for achieving body fixed hovering in proximity of the asteroid while ensuring that no impact will occur with the small body during the manoeuvre. Any chance of collision is ruled out thanks to a Lyapunov function controller which approaches the target Jacobi Energy without overshooting. Such a control law on the energy has to be always parallel to the instantaneous velocity vector while an additional steering law, normal to the velocity vector, takes care of pointing towards the target. Finally, we discuss the performance of the proposed approach by comparing it with the ZEM/ZEV control, another control law suitable autonomous guidance around small bodies which we also extend by incorporating the proposed three point-mass model of the gravitational potential.