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ANALYTICAL APPROXIMATIONS OF SPATIAL DISTANT RETROGRADE ORBITS

Abstract

Quasi-satellite orbits are orbits outside the Hill sphere of a celestial body. Their study is particularly relevant to the design of future space missions to small celestial bodies, such as asteroids, comets, and planetary satellites, whose libration points may be close to or even below the surface, since, in that case, all the orbits around such a body are quasi-satellite. These orbits can be used in applications such as the study and tracking of near-Earth objects and the building of infrastructure for circumlunar space exploration. Although one can numerically construct a quasi-satellite orbit for a specific problem, the analytical approach based on perturbation theory methods helps in studying the dynamics of quasi-satellite orbits and obtaining approximations useful for optimization procedures.

Probably the most important special case of quasi-satellite orbits are distant retrograde orbits (DROs) corresponding to the 1:1 mean motion resonance. In 2022, the Chang'e 5 orbiter has conducted very-long-baseline interferometry tests in a DRO around the Moon and was the first spacecraft in history to utilize the orbit. In November 2022, Artemis 1 entered a DRO and orbited the Moon. There are some other concepts that exploit this type of quasi-satellite orbits. DROs are considered by various space agencies as a platform for lunar orbital stations. Several proposals have been developed for a mission to the Kamoʻoalewa asteroid (2016 HO3) orbiting the Earth in a spatial DRO.

There is a rich literature on designing quasi-satellite orbits. Researchers considered different kinds of the three-body problem, but mostly focused only on the planar case. In this work, we apply the Hori–Deprit perturbation technique to approximate spatial DROs in Hill's problem and use this method to obtain analytical expansions up to the 7th order. We have also derived Fourier series expansions and, alternatively, applied symbolic regression, a technique that finds compact yet precise analytical formulas to express the numerical data. The orbits constructed by the three methods are compared with those obtained by numerical integration of the equations of motion in Hill's problem. The developed approximations will be useful to anyone dealing with DROs for various purposes, including understanding the orbital dynamics of natural celestial bodies and the spacecraft trajectory design and optimization.