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Representation of the Gravity Field of Irregularly Shaped Bodies

Stefan Reimond and Oliver Baur
Space Research Institute, Austrian Academy of Sciences, Graz, Austria (stefan.reimond@student.tugraz.at)

Exploratory space missions to small bodies in our solar system have gained importance over the last few decades. The well-renowned mission Rosetta set a milestone in space science history when it successfully lowered its mini-lab Philae onto the surface of Comet 67P/Churyumov–Gerasimenko in November 2014.
Knowledge of the gravitational field of a small body, e.g. a comet or asteroid, is crucial in order to study a spacecraft's motion in its environment and to infer geophysical properties. Traditionally, the gravitational field of a body is modeled by means of spherical harmonics. For bodies of near-spherical shape (such as the Earth), this is an adequate method, because the reference figure, i.e. a sphere, snugly fits the body. For irregularly shaped bodies, however, the adoption of spherical harmonics might be a sub-optimal choice. As an alternative, oblate or prolate spheroidal harmonics (OH or PH, reference figure is an ellipsoid of revolution) or ellipsoidal harmonics (EH, reference figure is a tri-axial ellipsoid) should be considered. The latter will in general be the best choice in terms of aptness of the reference figure. The downside of EH, however, lies in the considerably increased (numerical) complexity of the computation of the base functions, i.e. the Lamé functions of the first and second kind. OH or PH represent a promising path down the middle. Elongated bodies (such as Asteroid 433 Eros) are often similarly well approximated by a prolate spheroid as by the corresponding tri-axial ellipsoid. Contracted bodies, on the other hand, can be described accordingly well by means of an oblate spheroid.
We compare the SH, OH, PH and EH gravitational field parameterizations for different celestial bodies, including Rosetta's target comet 67P. The tasks are as follows: Based on the polyhedral representation of a body's shape model, the gravitational potential and acceleration vector is computed for evenly or irregularly distributed points inside or outside the respective reference figures. Real orbit data of the NEAR shoemaker is included as well. In a least-squares adjustment, these quantities serve as observations in order to determine the SH, OH, PH and EH series coefficients. Harmonic synthesis yields gravitational fields which are then compared with the corresponding forward-modeled data. Due to the various data distributions, conclusions can be drawn concerning the performance of the four methods both inside and outside their respective convergence regions.