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Using a Volume Discretization Method to Compute the Surface Gravity of Irregular Small Bodies† ⋆

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Abstract In the orbit design for small body exploration missions, it is important to take the effect of the gravitation of the small body into consideration. However, the majority of small bodies in the solar system are irregularly shaped with a non-uniform density distribution, this makes it difficult to precisely calculate the gravitational fields of these bodies. This paper proposes a method to model the gravitational field of an irregularly shaped small body, and calculate the corresponding spherical harmonic coefficients. This method is based on the shape of the small body resulted from the observed light curve, and uses finite volume elements to approximate the body shape. The spherical harmonic coefficients can be derived numerically by computing the integrals according to their definitions. A comparison is made with the polyhedron method. Taking the asteroid (433) Eros as an example, the spherical harmonic coefficients calculated by this method are compared with the result derived from the inversion of the NEAR (Near-Earth Asteroid Rendezvous) spacecraft' orbit data, and the comparison shows that the error of C_{20} is less than 2%. Using this method, we have calculated the gravity field of (1996) FG3 which is a candidate target in our future space exploration mission. Taking (4179) Toutatis, the target body of the Chang'e 2's flyby mission, as an example, the distribution of surface gravitational potential is calculated, in combination with the shape model derived from the radar data, it provides a theoretical basis for analyzing the surface soil distribution and flow direction from the optical images obtained in this mission. This method suits the objects of inhomogeneous density distribution, and can be used to provide the reliable gravitational data of small bodies for the orbit design and landing in future asteroid exploration missions.

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1. INTRODUCTION

In recent years, accompanying with the progress and development of space science and technology in the world, the asteroid exploration in the solar system has received more and more attention, an increasing number of asteroid exploration missions are planned and placed on the order of day. In the asteroid exploration mission, all the orbit design of the spacecraft, the landing and sampling on the asteroid have to take the effect of the asteroid's non-spherical gravitation into consideration. Most asteroids in the solar system are extremely irregular in shape, as the number of observed asteroids is rather small, the traditional method to derive the asteroid's gravitational field from the orbit data inversion of a flyby spacecraft can not be commonly used, we have to study the characteristics of gravitational field for this kind of small bodies using various observational data and corresponding algorithms, to build up a precise and reasonable model for the asteroidal gravitational field, and on this basis to study the orbit dynamics of the spacecraft in an irregular weak gravitational field. There are many methods for the gravity modeling of celestial bodies[1−2]. In 1966∼1967 Kaula and Heiskanen founded the theory of spherical harmonic function model, this method can approximate an arbitrarily shaped central body, it is the principal method for the gravity modeling of major planets in celestial mechanics. The spherical harmonic coefficients of gravity field can be determined also by the method of triaxial ellipsoid, but the accuracy of the result obtained by this method is rather low. In 1996, Weiner et al. proposed the method of polyhedron model, based on the observational data, this method uses a polyhedron with the surface that consists of multiple triangles to approximate the asteroid's shape, and derives the gravity field of the polyhedron model by an integral transform[3]. In 2010, Park et al. proposed a method for accurately modeling the gravitational field by combining the spacecraft's navigation data with the asteroid's shape model, to a certain extent this method has solved the difficulty of gravity modeling for the asteroids of density inhomogeneity, and improved further the modeling accuracy[4]. Also in 2010, Zhang Zhen-jian et al. proposed a method for the asteroid's gravity modeling and the derivation of spherical harmonic coefficients, in comparison with the traditional method, it has greatly improved the gravity modeling accuracy[5−6].

This paper proposes a method to model the gravitational fields of irregular asteroids and derive the corresponding spherical harmonic coefficients—the volume discretization method. In the light of finite element method, according to the asteroid's shape obtained from its light curve, this paper uses multiple finite volume elements to approximate the asteroid's volume, derives directly the spherical harmonic coefficients according to their definitions, so that to obtain the configuration of gravitational potential of the asteroid, and to calculate the distribution of its surface gravity. Taking (433) Eros as an example, the result obtained