"Higher Order Numerical Schemes for Simulation of Irregular Gravitational Fields."

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Background & Significance

Comets and asteroids belong to a class of celestial objects known as minor bodies. The solar systems minor bodies are of significant interest to the scientific community for several reasons. Many are akin to celestial fossils – persevering the makeup of the early solar system for our study. It has also been suggested that the resources contained within minor bodies could support an autonomous orbital economy driving down the prices of resources in space. Moreover, historic impacts have proven the grave consequences an impact event can have for life on earth. For all these reasons, Minor bodies have been the focus of several missions by national and international space organizations including: NASA, JAXA, ESA, ROSCOSMOS, CNAS. Over 20 probes have been sent to visit minor bodies in situ and this has created a need to properly characterize their gravitational fields. This task is complicated since minor bodies are typically highly irregular in shape. As such, to properly plan proximity operations high fidelity gravitational models are required.

Several such models exist for this application. Each has its strengths and weakness, and as such, each has particular tasks for which it is well-suited. Some applications have requirements that are not well-met by the currently available models. In particular, if population-based optimization strategies are to be used to optimize trajectories around small bodies many of the currently available models are too computationally expensive.

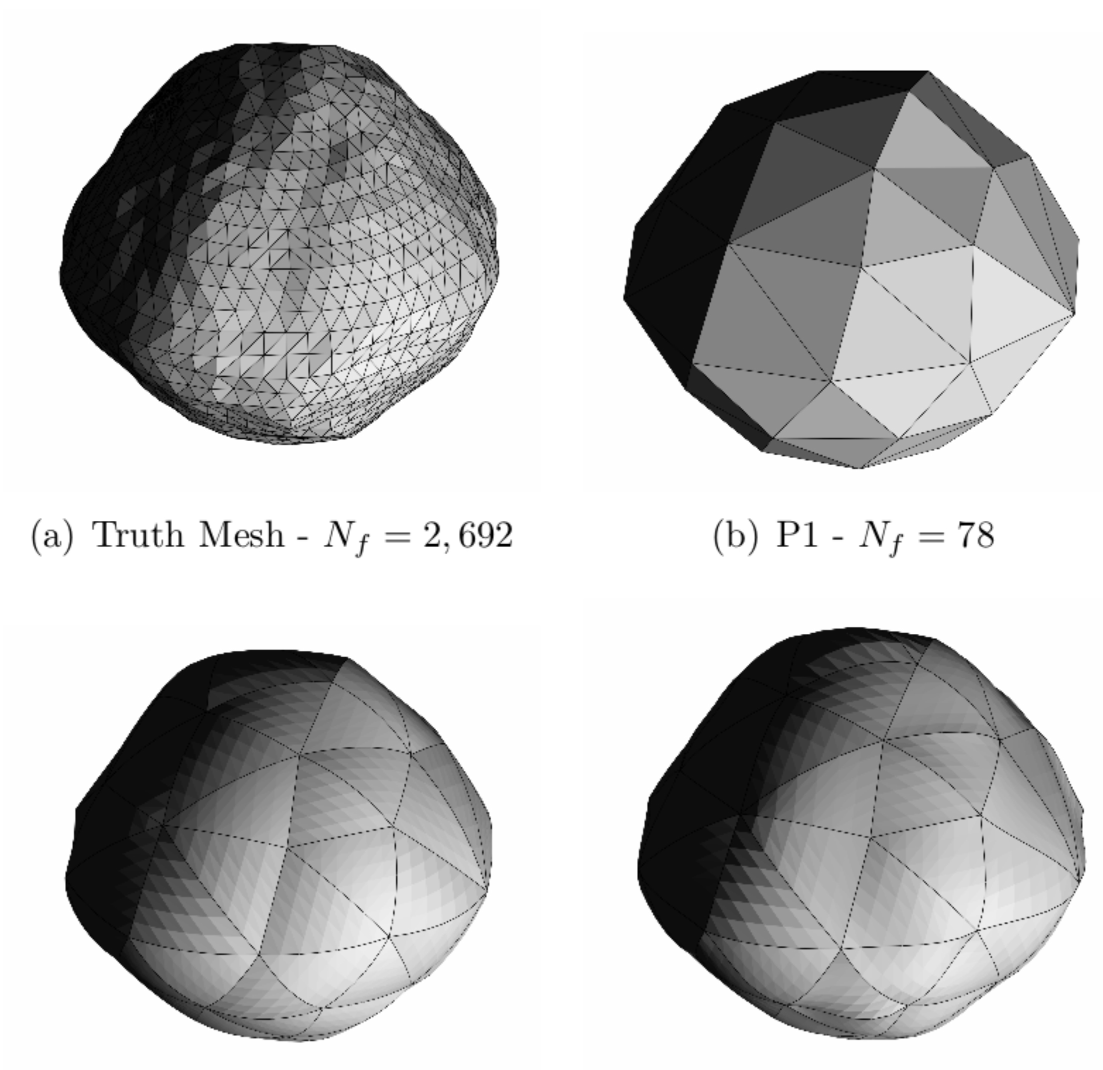
Project Goals

The project sought to develop a gravitational model suitable for population based trajectory optimization. It began with the analytic polyhedral model as a baseline. The analytic polyhedral model is one model that is commonly used to simulation the gravitational field of irregular bodies. The model analytically integrates over a triangular surface mesh of the body to approximate the gravitational field. It has many properties that make it well suited for the application; however, it is too computational intensive for use in population based optimizations. The goal of this work was to use a numerical integration technique known as numerical quadrature to speed-up the calculation. The new model needed to be fast enough to facilitate a multi-objective optimization of surface converge for Asteroid 101955 Bennu using NSGA-II with a differential evolution genetic operator.

Several parameters of the quadrature-based model were examined including the degree of exactness of the quadrature and degree of the geometric approximation. Recommendations regarding appropriate setting were made for particular applications.

Summary of Key Findings

The approximate polyhedral model developed as part of this work was found to be 20x faster than the analytic version. The approximate model introduces singularities to the surface of the acceleration calculation making it only suitable for applications that maintain an altitude greater than the mesh resolution. Additionally, it is not energy conserving and simple algebraic formulas have been developed to estimate this effect apriori. The approximate model is simpler to code as well. The approximate model is well-suited for applications were speed or simplicity of implementation are top priorities or when the potential is the only field of interest.



(a) Truth Mesh - $N_f = 2,692$ (b) P1 - $N_f = 78$

(c) P2 - $N_f = 78$ (d) P3 - $N_f = 78$

Figure 6.3: Example curvilinear surface definitions of Bennu.