GPU-accelerated algorithm for asteroid shape modeling

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Abstract

Modeling asteroid shapes from optical and radio telescope data is computationally expensive and current sequential-fit inversion algorithms are very slow, up until recently often taking days or weeks for larger models. The modeling process is comprised of many serialized independent calculations that can be parallelized with inexpensive and ubiquitous graphical processing unit (GPU) hardware. We have accelerated the SHAPE modeling algorithm (Hudson, 1994) with an Nvidia GPU and algorithm optimization while maintaining full backward compatibility, achieving speed boosts of 2.2x-19.3x over the established algorithm. The highest speed boosts achieved were for portions of the modeling process taking up a majority of processing time on the existing algorithm, moving the average speedup factor towards the upper end of the range.

We use scale model asteroids to show that our method can model shapes that are both unique to the observed data and stable. High resolution complex vertex models benefit the most from the new algorithm because of its better scalability to problem size on GPU hardware. Specific algorithm changes include facet-parallel rendering, pixel-parallel delay-Doppler mapping, parallel reductions, and streamed frame operations.

1. Introduction

Single-CPU sequential parameter fit methods for modeling asteroid shapes and associated parameters from observed data can be very time consuming while the inversion problem of asteroid shape reconstruction itself is quite suitable for some parallel processing (Ďurech et al., 2015).

The SHAPE algorithm, originally written for MPi clusters and single-CPU machines, is noted for its ability to use ground-based optical and radio telescope data. SHAPE remains the only package used in all published and in-progress radar-based shape/spin reconstructions (Hudson and Ostro, 1995; Nolan et al., 2013; Ostro et al., 2000; Scheeres et al., 2006). Asteroid shape modeling utilizing multiple data sources offers determination of the shape and other physical properties in one inversion process and has produced ‘spectacular results’ in the ADAM algorithm (Durech et al., 2015).

SHAPE projects a model asteroid into the space occupied by observed data, compares both and calculates the χ^2 error from the resulting sum of squares of residuals. The algorithm iteratively adjusts a specified series of model parameters in a sequential fit scheme that minimizes the χ^2 error via a bracket and Brent method (Press et al., 1992). This approach requires many repeated model renderings and Doppler/delay-Doppler mappings for each parameter adjustment, looped until a specified χ^2 error threshold is reached.

Even with modern CPUs, SHAPE is very slow: the final modeling step for a 40,000-facet model of 4179 Toutatis takes 25 hours for a single iteration through 20,232 parameters with 401x401

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