MULTIPLE MODEL PROPAGATION OF HIGH AREA-TO-MASS (HAMR) OBJECTS USING AN ENCKE TYPE CORRECTION ALGORITHM

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ABSTRACT

The propagation of high area-to-mass ratio (HAMR) objects is a challenging problem because of the significant effect that non-conservative attitude dependent forces exert on these objects. Given that attitude dynamics may be several orders of magnitude faster than orbit dynamics, the combined effect of all forces acting on a HAMR object can be accurately captured only if all forces are evaluated at a correspondingly higher frequency. In addition to attitude dependent forces, this involves evaluation of the gravitational potential, third-body gravity contributions, gravitational effects of tides for LEO objects, etc. The influence of changing attitude on such forces is only indirect: through the changes in object's position effected over time by the attitude dependent forces. Conversely, the influence of changing position and velocity on the attitude dependent torques is typically very small due to their "differential" nature: these torques arise from the difference that corresponding forces apply across the extent of an object. Hence, small changes in position and velocity produce only secondary effect on the torques.

In 2001, Woodburn and Tanygin [1] proposed an Encke type correction algorithm for numerical integration that takes advantage of these characteristics of the propagation environment. It provides a computational advantage over the fully coupled propagation by avoiding the evaluation of the dominant gravitation related forces at the high frequency demanded by the attitude dynamics. Instead, the Encke type correction is applied via a secondary integration that includes all attitude dependent effects plus the difference in the two body accelerations between the corrected and uncorrected trajectories. The algorithm uses this integrated correction to rectify the orbit state after every main integration step which enables it to attain a better accuracy than a simple decoupled approach. For a tumbling cylinder in LEO, Woodburn and Tanygin demonstrated that their method saves up to 20% of computation time with a 12x12 degree and order truncation of the gravity potential and more with higher fidelity models, close to 75% savings with a 50x50 model. This was achieved while maintaining accuracy of better than 50 cm after 1 hour of propagation.

This paper examines performance of the original algorithm for a wider range of orbit regimes, object shapes and attitude motions. It also introduces a modification of the algorithm for multiple model propagation (MMP). MMP involves numerical integration of multiple object models that differ in shape, mass properties and possibly initial attitude. These are used in a bank of parallel filters that eventually settle on the most probable model via a process called multiple model estimation (MME) [2]. The expense of running full numerical integrations of multiple competing models can be mitigated by running a full numerical integration for only one nominal model and integrating just Encke type corrections for all other models. In this case, rectification is not applied until the MME algorithm settles on a single most probable model (or on a subset of most likely models). Linares et al. [2] demonstrated that a correct model for objects in near GEO in a

continuously-lighted trajectory can be discerned from a bank of five possible models after about 30 astrometric and photometric measurements, which amounts to about 15 min of propagation time. It is expected that even without rectification the integrated Encke corrections in near GEO will remain small over this interval. This allows a bank of several models to be integrated significantly faster because all of the competing models can reuse the same reference (uncorrected) trajectory. For example, based on the original results of Woodburn and Tanygin [1], integrating five object models with a 12x12 gravity potential model can be expected to save significantly more than 20% of computation time, with the savings being proportional to the number of models. This should provide an opportunity to improve the shape and attitude estimation of the HAMR objects by evaluating a greater number of competing models within the same computational constraints.

References

[1] Woodburn, J. and Tanygin, S., "Efficient Numerical Integration of Coupled Orbit and Attitude Trajectories Using an Encke Type Correction Algorithm," Paper AAS 01-428, AAS/AIAA Astrodynamics Specialist Conference, Quebec City, Quebec, Canada, July 30-August 2, 2001.

[2] Linares, R., Crassidis, J. L., Jah, M. K., and Kim, H., "Astrometric and Photometric Data Fusion for Resident Space Object Orbit, Attitude and Shape Determination Via Multiple-Model Adaptive Estimation," Paper AIAA 2010-8341, AIAA Guidance, Navigation and Control Conference, Toronto, Ontario, Canada, August 2 - 5, 2010.