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# A MODEL FRAMEWORK FOR HIGH-ACCURACY, SHORT- AND LONG-TERM ORBIT DETERMINATION AND PROPAGATION OF CISLUNAR SPACE DEBRIS, WITH REALISTICALLY QUANTIFIED UNCERTAINTIES

**Abstract**

Cislunar space is getting increasingly important. Countries like the US and China are directing their attention towards the Moon with the Artemis and Chang'e missions. Simultaneously, space debris pollution of the orbits is escalating. Currently, there are four times as many pieces of space debris (>10 cm) than there are functional objects in space. Cluttering of Earth's orbits increases the risk of the Kessler syndrome occurring. Space Situational Awareness (SSA) aims to prevent this.

The sheer amount of space debris makes continuous tracking infeasible. It is therefore important to be able to propagate space debris orbits accurately in between observations. Model frameworks have been developed extensively for space debris in near-Earth orbits, but there is little experience with Cislunar space. This region is more challenging because of its unstable nature, causing a higher risk of losing track of objects.

In this research, a model framework is developed, using open-source software Tudat, that can estimate short- and long-term Cislunar space debris accurately from astrometric data, whilst also quantifying the uncertainties realistically over time.

We apply our framework to the Chang'e 2 and 3 upper stages. Both objects have ∼10 years of observations, allowing analysis for a diverse range of orbital characteristics. Orbit determination has been performed using Weighted Least-Squares. The algorithm can estimate (amongst other things) initial states of the objects, model parameters like radiation pressure properties, and observation biases.

First, a benchmark model framework has been developed with an optimal accuracy to computational load trade-off. Important design choices are dynamical models, integrator, and propagator settings. The algorithm is built flexibly, allowing different design configurations to run concurrently. Analyzing in-sample and out-of-sample accuracy for each configuration prevents overfitting. Using the benchmark, the effect of various orbit characteristics on propagation accuracy is analyzed.

Furthermore, estimating on optical observations for Cislunar space debris involves a variety of uncertainties. Model uncertainties like the radiation pressure coefficient and observation biases have large influences on the propagation. We will present results on the effect of these uncertainties over time for various Cislunar orbit types, propagated using Monte Carlo simulation.

Finally, using propagation accuracy and estimated uncertainty over time, the risk of Cislunar space debris being lost to observers over a given period is quantified. High risk means new observations are required to run the orbit determination algorithm again. Contributing to Cislunar SSA, this model framework shows any observer what Cislunar space debris to track.