Small Debris Estimation Approach Using Sparse Sampling to Infer Markov Steady State Distributions

Richard Kim

(1) Stanford University, 475 Via Ortega, Stanford, CA 94305-6015 United States

ABSTRACT

Space systems are a vital part of the global information-sharing infrastructure. The strategic utility of space as an operating environment enables services such as precision navigation and timing, weather forecasting, and communications. While space is becoming increasingly utilized by a growing number of space-faring nations and organizations, the environment continues to become increasingly cluttered with debris particles.

Large debris particles can be tracked using space surveillance sensors, and well-established algorithms can predict conjunctions with enough lead time for a satellite operator to employ a countermeasure. Very small debris particles (such as nanoparticles), cannot be detected by space surveillance sensors, but have sufficiently low mass that they do not pose a practical threat to operational satellites. In between these two classes of particles, there exists a range of debris, in size and mass, which are too small to be detected by space surveillance sensors, but still pose a threat to satellite operations. We refer to debris particles that lie in this observability-risk class (nominally $10^{-4}$ to $10^{-1}$ meters in apparent diameter) as minimally observable destructive debris (MODD) particles.

While active tracking of MODD particles is a desired outcome, the physical and economic limitations associated with sensor phenomenologies of conventional space surveillance sensors, such as the diffraction limit of electro-optical sensors, make this a practical impossibility. Instead, a more reasonable objective is to characterize the spatial density of MODD particles and build probabilistic distributions. It may be possible to collect data on the presence of MODD particles using impact plates which are launched into various orbits for the purpose of collecting impact signatures. Then the challenge lies in how to characterize the distribution of MODD particles, on the basis of sparse observable data from collection methods such as impact plates. Therefore, the research question that we pose is: What is the optimal data collection policy to maximally recover the true distribution of MODD particles, given sparse and irregular data collection opportunities?

The approach that we use is to frame the distribution of MODD particles as a discrete state space, finite time Markov process. Given this framework, we attempt to recover estimates of the true steady state distribution from the sparsely sampled data. From the observable data, we reconstruct an estimated Markov process and use detailed balance conditions to estimate the true steady state distribution of MODD particles. The objective is to find an optimal data collection policy to help inform mission requirements for such a data collection campaign.

Keywords: small debris, stochastic modeling, stochastic control, Markov processes