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NON-LINEAR BAYESIAN ORBIT DETERMINATION: ANGLE MEASUREMENTS

Abstract

Situational awareness of Earth-orbiting particles such as active satellites and space debris is known to be a *data starved* problem compared to traditional estimation problems in that objects may not be observed for days if not weeks. Therefore, consistent characterization of the uncertainty associated with these objects is crucial in maintaining an accurate catalog of objects in Earth orbit. For instance, the topology of observational uncertainty is significantly influenced by the type of observation made. Simultaneously, the motion of satellites in Earth orbit is *well-modeled* in that it is particularly amenable to having their solution and their uncertainty described through analytic or semi-analytic techniques. Even when stronger non-gravitational perturbations such as solar radiation pressure and atmospheric drag are encountered, these perturbations generally have deterministic components that are substantially larger than their time-varying stochastic components.

In this paper, we present a non-linear Bayesian approach to orbit determination that takes into account the above properties of space situational awareness (SSA) and thus is well-suited for such a task. Namely, we leverage the highly directional spread of uncertainty for optical observations of Earth-orbiting objects and the deterministic nature of the dynamical environment. Optical observations are expressed as probability density functions (pdfs) called *admissible regions* that predominantly span in the range and range-rate directions. Consequently, in the state space, the admissible region is realized as a nearly two-dimensional manifold with a small âœthicknessâ corresponding to the errors in angle and angle-rates. These pdfs, along with any other pdfs associated with tracked objects or uncorrelated tracks (UCTs), are propagated analytically and non-linearly via a special solution to the diffusionless Fokker-Planck equation. The solutions to the dynamics are expressed as an arbitrary order Taylor series expansion, or *state transition tensors* (STTs). STTs are defined even for systems with no exact closed-form solutions. Furthermore, model parameter uncertainty, such as those for atmospheric drag, is readily implemented. The pdfs are then combined via Bayes' rule, allowing for an apples-to-apples comparison between any probabilistic data. Due to the large uncertainties and potentially long mapping time-spans, even initially Gaussian pdfs become significantly non-Gaussian. Our theory provides a semi-analytical framework for dealing with these situations that is distinct from other approaches currently being developed in the field.