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New Methods in Optical Track Association and Uncertainty Mapping of Earth-Orbiting Objects

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As more and more sensing capabilities for space surveillance are introduced, we expect that both correlated and uncorrelated tracks of resident space objects will drastically increase. Existing observation association techniques rely on simplified dynamics, *ad hoc* association criteria, and linear propagation of Gaussian uncertainty. To maintain an accurate catalog of resident space objects now and into the future, however, a more consistent description of the uncertainty associated with said objects is desired. Two characteristics of the space situational awareness problem are applicable to this goal: that the type of observation significantly influences the geometry of the observational uncertainty, and that the dynamical system is amenable to analytic or semi-analytic solution techniques. In this dissertation, each of these characteristics are examined and ultimately applied to the problem of optical track association, often referred to as the too-short arc problem.

First, an analytical method of non-linear uncertainty propagation is discussed. A special solution to the Fokker-Planck equations for deterministic systems and the state transition tensor concept are combined so that, given an analytical expression of both the initial probability distribution and the dynamics, the probability distribution may be expressed analytically for all time. Next, an observation association technique is proposed which involves admissible regions: probability density functions representing not only the measurement errors but also the limited knowledge in the unobserved variables. Bayes' rule is directly applied to associate multiple observations and subsequently obtain an orbit estimate. A quantitative argument on the effects of measurement errors on the admissible region, and consequently direct Bayesian track association, are also given. Finally, the proposed approach to short-arc association and initial orbit determination are applied to optical observations taken at the Astronomical Institute of the University of Bern. In addition to matching over half of the objects detected by conventional techniques, the proposed method finds two additional objects at or near geostationary altitude, all without *a priori* information.