ABSTRACT

NONLINEAR TRAJECTORY NAVIGATION

by

Sang H. Park

Chair: Daniel J. Scheeres

Trajectory navigation entails the solution of many different problems that arise due to uncertain knowledge of the spacecraft state, including orbit prediction, correction maneuver design, and trajectory estimation. In practice, these problems are usually solved based on an assumption that linear dynamical models sufficiently approximate the local trajectory dynamics and their associated statistics. However, astrodynamics problems are nonlinear in general and linear spacecraft dynamics models can fail to characterize the true trajectory dynamics when the system is subject to a highly unstable environment or when mapped over a long time period. This limits the performance of traditional navigation techniques and can make it difficult to perform precision analysis or robust navigation.

This dissertation presents an alternate method for spacecraft trajectory navigation based on a nonlinear local trajectory model and their statistics in an analytic framework. For a given reference trajectory, we first solve for the higher order Taylor series terms that describe the localized nonlinear motion and develop an analytic expression for the relative

solution flow. We then discuss the nonlinear dynamical mapping of a spacecraft's probability density function by solving the Fokker-Planck equation for a deterministic system. From this result we derive an analytic method for orbit uncertainty propagation which can replicate Monte-Carlo simulations with the benefit of added flexibility in initial orbit statistics.

Using this approach, we introduce the concept of the statistically correct trajectory where we directly incorporate statistical information about an orbit state into the trajectory design process. As an extension of this concept, we define a nonlinear statistical targeting method where we solve for a correction maneuver which intercepts the desired target on average. Then we apply our results to a Bayesian filtering problem to obtain a general filtering algorithm for optimal estimation of the *posterior* conditional density function incorporating nonlinearity into the filtering process. Finally, we derive practical Kalman-type filters by applying our nonlinear relative solutions into the standard filters and show that these filters provide superior performance over linear filtering methods based on realistic trajectory and uncertainty models. The examples we consider are a conventional Hohmann transfer from the Earth to Moon using a simple two-body model, a strongly unstable transfer trajectory in the Hill three-body problem from the vicinity of L_2 through several orbits, and to the navigation of a spacecraft in a halo orbit in the restricted three-body problem. For each of these examples we show the benefits of using our nonlinear trajectory navigation techniques as compared to traditional linear navigation techniques.