CURRENT-STATE CONSTRAINED FILTER BANK FOR WALD TESTING OF SPACECRAFT CONJUNCTIONS

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ABSTRACT

We propose a filter bank consisting of an ordinary current-state extended Kalman filter, and two similar but constrained filters: one is constrained by a null hypothesis that the miss distance between two conjuncting spacecraft is inside their combined hard body radius at the predicted time of closest approach, and one is constrained by an alternative complementary hypothesis. The unconstrained filter is the basis of an initial screening for close approaches of interest. Once a conjunction passes the initial screen, the unconstrained filter also governs measurement editing for all three filters, and predicts the time of closest approach. The constrained filters operate only when conjunctions of interest occur. The computed likelihoods of the residuals of the two constrained filters form a ratio for a Wald sequential probability test. The Wald test guides risk mitigation maneuver decisions based on explicit false alarm and missed detection criteria, which can be informed by Bayesian utility theory.

Since only current-state Kalman filtering is required to compute the residuals for the likelihood ratio, the present approach does not require the mapping of probability density forward to the time of closest approach. Instead, the hard-body constraint manifold is mapped to the filter update time by applying a sigma-point transformation to a projection function. Although a multiplicity of projectors are possible, we choose one based on Lambert-style differential correction of the current-state velocity.

Our approach may offer several advantages with respect to the current state of the practice for conjunction assessment, which is primarily based on attempts to explicitly compute collision probability. It does not require approximate solutions to the Fokker-Planck-Kolmogorov partial differential equation for mapping probability densities through time. It does not require approximations to integrals of probability density to compute a collision probability. It does not require arbitrary thresholding of acceptable collision probability values, or other arbitrary factors associated with the character of the conjunction.

We have tested our method using a scenario based on the Magnetic Multi-Scale mission, scheduled for launch in late 2014. This mission involves formation flight in highly elliptical orbit of four spinning spacecraft equipped with antennas extending 120 meters tip-to-tip. Eccentricities range from 0.82 to 0.91, and close approaches generally occur in the vicinity of perigee, during which time rapid changes in geometry may occur. Testing the method using a 40,000-case monte carlo simulation, we found the method achieved a missed detection rate of 0.47%, and a false alarm rate of 0.34%.