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DYNAMIC CHARACTERISATION OF SPACE DEBRIS POSITION AND VELOCITY PROBABILITY DENSITY FUNCTIONS AND THEIR IMPACT ON TRACKING PERFORMANCE

Abstract

With increased space objects in near-earth space, accurate and consistent collision probability computation has become crucial, more than ever, for the safety of active satellites. Collision probability calculation requires space debris tracking information. Usually, tracking, i.e., position and velocity estimation of space objects from external observations such as range, range rate and angle measurement, is performed using sequential estimators, for example, the Extended Kalman Filter (EKF). The EKF is a sub-optimal estimator that propagates the error covariance through linear approximation. It should be noted that the EKF does not provide the complete Probability Density Function (PDF) as an output. A common practice is to assume the posteriori PDF is a normal distribution parametrised by the a posteriori mean and error covariance matrix provided by the EKF. Many researchers have criticised this approach of linear covariance propagation (which implies linear PDF propagation) and the Gaussian assumption of the posterior density. However, the quantification of error due to these assumptions is not well explored in the Space Situational Awareness (SSA) context. This article focuses on understanding the dynamic characteristics of the position and velocity PDFs of space objects in the Earth's gravitational field and quantifying the error incurred due to the linear PDF propagation and Gaussian PDF assumption. The analysis assumes the initial position and velocity PDF as uniform. This initial PDF is propagated using the Fokker-Planck Equation (FPE), considering the non-linear equation of motion of the space object. Considering noisy ground-based range, azimuth and elevation observations, the Cramer Rao Lower Bound (CRLB) of the position and velocity estimation is computed using the non-linearly propagated PDF and the linearly propagated and Gaussian PDF separately. The difference between the CRLBs computed using the two methods signifies the expected accuracy difference in state estimation considering non-linear PDF propagation and the same considering linear propagation of Gaussian PDF. In addition, this analysis is performed by varying eccentricity and orbit altitude to observe the variation in the performance difference mentioned above. This analysis will explicitly aid the designers of space object tracking algorithms in selecting estimation algorithms for SSA.