Filter Tuning Using the Chi-Squared Statistic

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ABSTRACT

The NASA Goddard Space Flight Center (GSFC) Flight Dynamics Facility (FDF) performs orbit determination (OD) for the Aqua and Aura satellites. Both satellites are located in low Earth orbit (LEO), are part of the "A-Train satellite" constellation, and are currently in the science phase of their respective missions. The FDF has recently been tasked with delivering definitive covariance for each satellite.

The main source of orbit determination used for these missions is the Orbit Determination Toolkit (ODTK) developed by Analytical Graphics Inc. (AGI). This software uses an Extended Kalman Filter (EKF) to estimate the states of both spacecraft. The filter utilizes ground station measurements, space network measurements and force modeling to determine spacecraft states. It also computes a covariance matrix with each state. This covariance matrix is useful for evaluating the overall performance of the filter and is useful for covariance propagation. The propagated covariance is utilized to determine if the current orbital solution will meet mission requirements in the future and to improve collision avoidance operations.

This paper examines the use of the Chi-squared statistic as a means of evaluating filter performance. The practical application of this statistic is discussed in a technical memorandum by M.D. Hejduk. The Chi-squared statistic is calculated to determine the realism of a covariance based on the prediction accuracy and the covariance values at a given point in time. More precisely, it is the sum of those ratios on each of the three degrees of freedom of the satellite's position. Once calculated, the distribution of this statistic provides insight on the accuracy of the covariance.

For the EKF to correctly calculate the covariance, error models associated with tracking data measurements must be accurately tuned. Incorrectly estimating these error values can have detrimental effects on the overall filter performance. The filter incorporates ground station measurements, which can be tuned based on the measurement noise of the individual ground stations. It also includes measurements from the NASA Space Network (SN), which can be affected by the accuracy of the Tracking and Data Relay System satellite state at the time of the measurement.

The force modelling in the EKF also affects the propagation accuracy and covariance sizing. The dominant force in the LEO orbit regime is atmospheric drag. Accurate accounting of the drag force is especially important for the accuracy of the propagated state. The implementation of a box and wing model to improve drag estimation accuracy and its overall effect on the covariance state is explored.

The process of tuning the EKF for Aqua and Aura support is described, including an examination of the measurement errors of available observation types (Doppler and range) and methods of dealing with potentially volatile atmospheric drag modeling. Predictive accuracy and the distribution of the Chi-squared statistic, calculated based of the ODTK EKF solutions, are assessed against accepted norms for the orbit regime.