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ANALYTIC SPACECRAFT ATTITUDE AND RATE ESTIMATION PERFORMANCE DURING ATTITUDE SENSOR OUTAGES

Abstract

Analytic expressions for spacecraft attitude and rate estimation performance of an attitude estimation filter in terms of sensor specifications are useful tools for spacecraft design. Farrenkopf famously found analytic expressions for steady-state pre-update and post-update attitude and gyro bias estimate error variances for an attitude estimation filter for a single-axis spacecraft with an Angular Rate Gyro (ARG) modeled as having an unstable bias and angle random walk noise. Markley and Reynolds extended the analysis for a Rate Integrating Gyro (RIG) with an unstable bias, angle random walk noise, and angle white noise. These expressions allow for the rapid evaluation of system performance during preliminary mission design phases, which is useful for selecting hardware, as well as providing a basis for evaluation of high-fidelity 3 axis attitude estimation filter performance. One contribution of this paper is the analytic calculation of the steady-state pre-update and post-update angular rate estimate uncertainty for both the ARG and RIG cases.

The primary contribution of this paper is the extension of the results for both the ARG and the RIG cases to the situation of an attitude sensor outage. During an attitude sensor outage, the estimation algorithm's estimates must be propagated by the gyro alone. This situation arises frequently in practice, for example when a star sensor's field of view is occluded, or when a star sensor's readings are unreliable during a thruster burn that vibrates the spacecraft, or during star sensor outages due to radiation. Analytic expressions for the attitude estimate uncertainty, gyro bias estimate uncertainty, and angular rate estimate uncertainty are given in terms of the attitude sensor outage interval, the star tracker measurement noise, and gyro noise parameters for unstable bias noise and angle random walk noise (and angle white noise in the RIG case).

The utility of the analytic tools are demonstrated numerically. The parameters for the noise models of the ARG and RIG are related to noise specifications commonly given on manufacturer datasheets. Two example cases are given for illustration. Finally, plots of performance as a function of the various noise parameters for the ARG and RIG cases are given for both steady-state filter operation and for an attitude sensor outage scenario.