SYNOPTIC: Estimation of the Length and Orientation of the Line between Two Closely Co-Orbiting Satellites, John Hrastar, NASA Goddard Space Flight Center, Greenbelt, Md.; *Journal of Spacecraft and Rockets*, Vol. 7, No. 10, pp. 1178–1182.

Earth Orbital Trajectories; Spacecraft Tracking

Theme

A combination of data from onboard sensors and ground tracking data is used to estimate the vector between two closely co-orbiting satellites. The importance of properly defining the variables to be estimated, so the estimate errors remain low, is discussed.

Content

For two closely co-orbiting satellites (the baseline or line between them is much less than the respective orbital radii), the length and orientation of the baseline cannot be estimated accurately with ground tracking measurements alone. The problem may be solved using the information from three simple sensors on board one of the satellites as well as ground tracking information.

The equations of motion of the two satellites are linearized with respect to the nominal circular orbit. An inertial coordinate system is centered with respect to this orbit plane with the X-Y axes in the plane. The baseline can be specified by its length and two angles relative to the axes in this plane. If the projection of the baseline on the nominal orbit plane makes an angle γ with the X axis, the first variation in γ is

$$\delta\gamma = -(1/B_0)(\delta q_1 - \delta p_1) + (1/2R_0)(\delta q_2 - \delta p_2) \qquad (1)$$

where q_1, p_1 are the radial distances to the two satellites; q_2, p_2 are distances along the trajectory of the two satellites; B_0 is the nominal baseline length; and R_0 is the nominal orbit radius.

Equation (1) is typical in that the components of the q and p state vectors show up as sums and differences. A new set of state variables is defined as the sums and differences of δp_i's and δq_i's.

$$x_i \begin{cases} \delta q_i - \delta p_i & i = 1,2,\ldots,6 \\ \delta q_{i-6} + \delta p_{i-6} & i = 7,8,\ldots,12 \end{cases} \qquad (2)$$

Some of the variables are assumed to be estimated solely from ground observations. These estimates are combined with the onboard sensor data and used with a Kalman filter to estimate the remaining variables. The estimates of all the x_i are used to estimate the two angles and baseline length.

The estimate of the first variation in γ is

$$\delta\hat{\gamma} = -(1/B_0)\,\hat{x}_1 + 1/2R_0\,\hat{x}_8 \qquad (3)$$

The variance of the estimate error is bounded by

$$\sigma_{\gamma^*}{}^2 = (\sigma_1{}^2/B_0{}^2) + (\sigma_8{}^2/4R_0{}^2) + (\sigma_1\sigma_8/R_0B_0) \qquad (4)$$

Since $B_0 \ll R_0$, this is approximately $\sigma_1{}^2/B_0{}^2$. The variable x_8 is estimated from ground observations and x_1 is estimated primarily from onboard data. The variance $\sigma_1{}^2$ is much less than $\sigma_8{}^2$, and therefore $\sigma_{\gamma^*}{}^2$ is relatively independent of the large errors associated with the ground tracking information.

A digital simulation was carried out with the following parameters: $R_0 = 7 \times 10^7$ ft, $B_0 = 10^4$ ft. The onboard sensors were assumed to have white, zero-mean Gaussian noise with standard deviations $\sigma_{v1} = 5$ ft, $\sigma_{v2} = \sigma_{v3} = 0.5°$. The value of σ_8 was assumed to be 300 ft.

The simulation showed that good estimates of the x_i were available after about 5000 sec. The standard deviations of the estimate errors of the two angles defining baseline orientation were 0.2° and 0.14°. The standard deviation of the estimate error of the baseline length was 2.5 ft. These results could not have been achieved with ground tracking measurements alone.