Orbital Navigation using Resident Space Object Observations

Matthew Driedger, Valorie Platero, Philip Ferguson
Department of Mechanical Engineering, University of Manitoba
matt.driedger@umsats.ca; valorie.platero@umsats.ca; philip.ferguson@umanitoba.ca

Simulation Results

We ran the simulation with various RSO/Star scenarios as detailed below. For each test, the observer was in a 400 km circular orbit and the observed RSOs/stars were stationary.

<table>
<thead>
<tr>
<th>Test Scenario</th>
<th>Measurement Sources</th>
<th>Convergence Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stars Only</td>
<td>4x stars</td>
<td>Position does not converge</td>
</tr>
<tr>
<td>RSOs Only</td>
<td>3x 30,000 km RSOs</td>
<td>0.46 observer orbits</td>
</tr>
<tr>
<td>RSOs and Distant RSOs</td>
<td>4x stars</td>
<td>0.36 observer orbits</td>
</tr>
<tr>
<td>Stars, Distant, and Near RSOs</td>
<td>4x stars</td>
<td>0.24 observer orbits</td>
</tr>
</tbody>
</table>

The above simulation results demonstrate that the estimator does not require star measurements to resolve position and attitude estimates. Measurements from only RSOs eventually lead to convergence following a significant change in observer perspective caused by orbital motion. The addition of star measurements significantly improve convergence time.

Conclusions

Accurate observer state estimation is possible when RSO/star state data is known. Convergence occurs quickly with ≤ 6 observed bodies. Future work will expand these results with more realistic orbital dynamics and measurement models.

Background

Star trackers are capable of identifying resident space objects (RSOs). Currently, star tracker software rejects RSO images, but could these RSO measurements improve orbital navigation?

Hypothesis

If the orbital parameters of observed RSOs are available, a spacecraft can determine its position, attitude, and rates by observing these RSOs.

Measurements

Simplified to two dimensions, and assuming the state of the observed RSO or star is known, the relationship between an observer and an RSO or star is:

\[ z = \text{Observation Angle} = \tan^{-1} \frac{\Delta y}{\Delta x} - \text{Observer Attitude} \]

As a star’s position is near-infinite, stars and RSOs provide complementary observer-state data:

\[ z = \text{star meas. object meas.} = Hx = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} x \]

Extended Kalman Filter

We used an Extended Kalman Filter to estimate observer-satellite’s state using RSO/star measurements. The EKF provides rate information and linearizes the non-linear measurement equation.

Instantaneous observability of our state measurements is demonstrated by the invertibility of \( H^T H \) for any non-zero observation matrix \( H \) (with a reasonable magnitude).

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