

Absolute and Relative Estimation for Satellite Formations

By Jack Goetz

Introduction

As part of a grant from the General Dynamics corporation, I am exploring methods of implementing an estimation algorithm in the form of a SIMULINK model that will take measurement data and return an estimate of a chaser satellite relative to a host satellite. This project provides the input to a control system that can be used to generate specific relative orbits of the chaser about the host that may be necessary for a variety of missions.

Absolute Estimators

Currently there are two de-coupled estimators working to provide a position for the chaser satellite. The first estimator accepts a measurement, in the current configuration this is a range from a ground station, and uses that measurement in conjunction with an initial condition and a dynamic model to return an estimated current state. The estimator itself uses an extended form of the Kalman filter algorithm which updates state and covariance at each time step. An image of the SIMULINK model can be seen below in Figure 1.

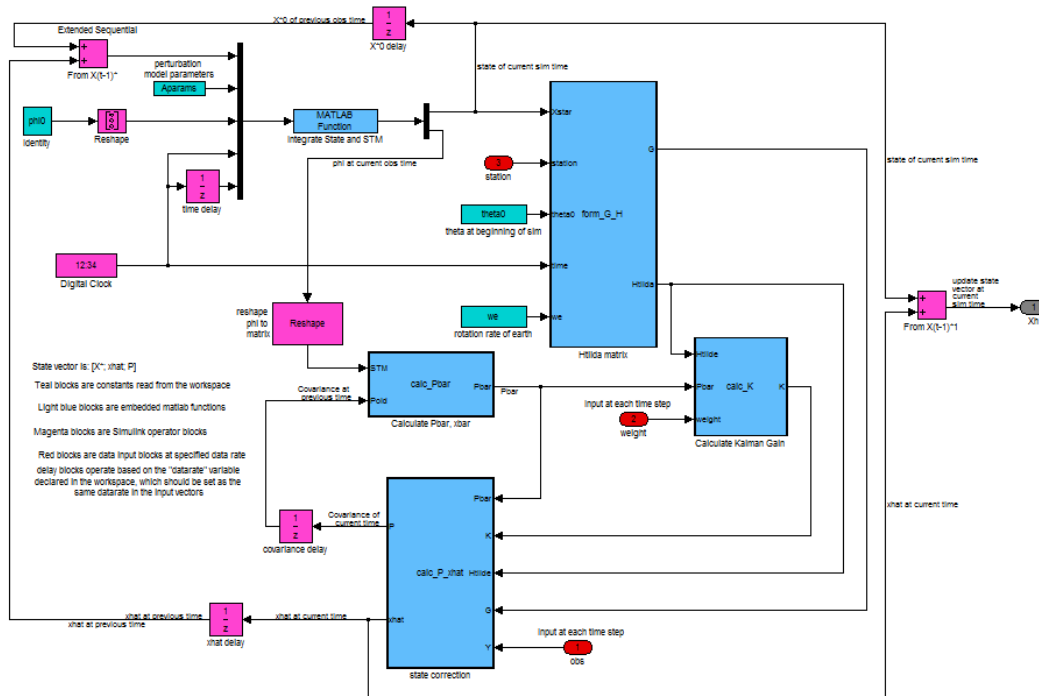


Figure 1: Absolute estimation algorithm in SIMULINK

This model was built to be flexible and can accept any rate of measurement data and an update to the dynamic model requires the editing of only a single block.

Relative Estimator

The relative estimator has nearly the same form as the absolute estimator. Instead of a ground station range, the relative estimator utilizes a range measurement between the two satellites to perform state updates. Also, since the relative estimator is based on the Clohessy-Wiltshire equations, which are linear and do not require integration of a state transition matrix, there is no integrator block in this model. The SIMULINK model for this estimator is seen below in Figure 2.

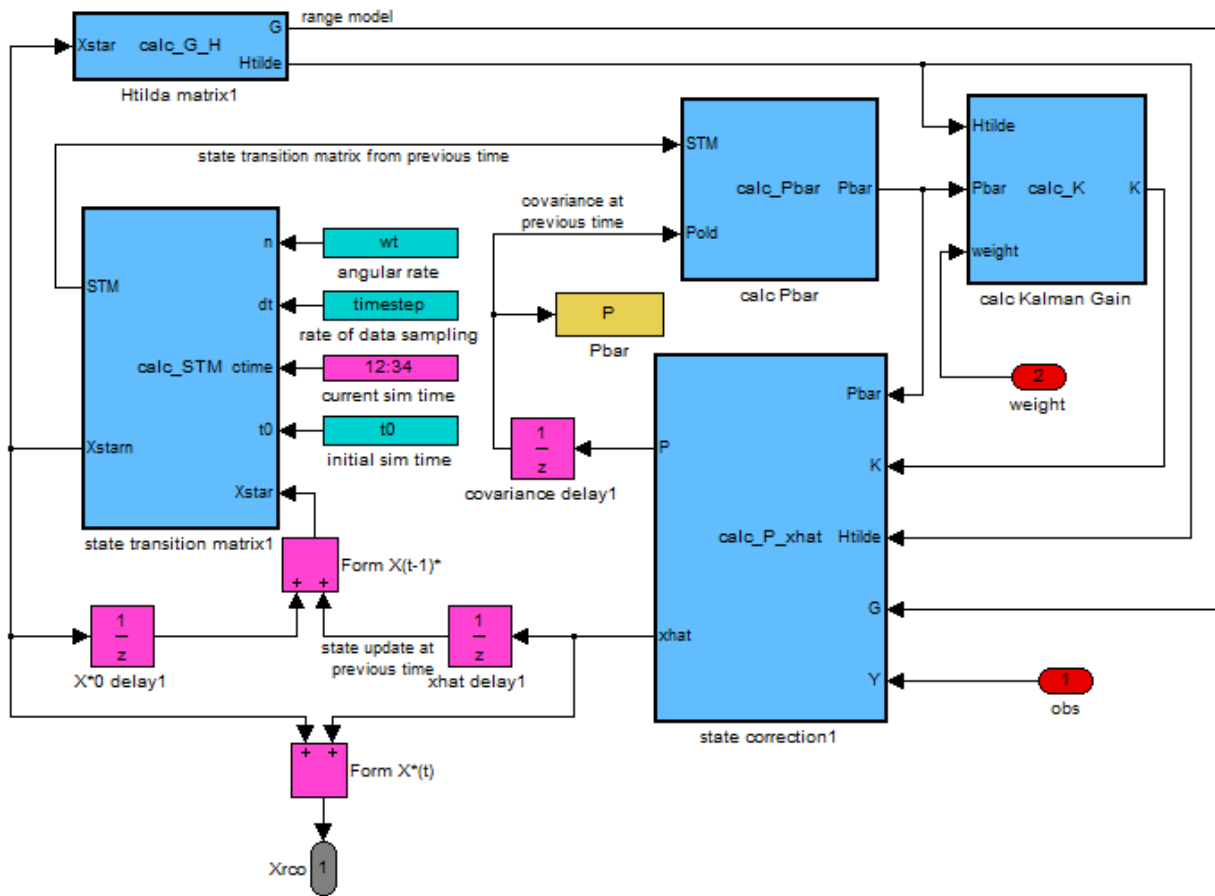


Figure 2: Relative estimation algorithm in SIMULINK

The two estimations generated by the measurements can be combined to provide an absolute estimate for the chaser satellite which is required for performing course adjustments in a control algorithm. Currently only the absolute estimator includes perturbation effects, such as drag and J_2 , in its dynamic model. Future work will include re-deriving the CW equations with drag and J_2 accounted for and merging the estimation algorithm with the control algorithm

Results

The following show the results of a test of the two estimation algorithms with initial conditions set up to provide a closed chaser orbit. Figure 3 shows the earth and the absolute orbits of both satellites. A more interesting plot can be seen in Figure 4 and Figure 5, which shows the norm of the position error and how it decreases over time as a result of the Kalman filtering. Finally Figure 6 and Figure 7 show the evolution of the covariance matrix and how it is reduced close to zero, but is not zero, indicating that the filter knows the position of the satellite well but is not entirely discounting the contributions of new measurements (as a would be indicated by a zero covariance matrix).

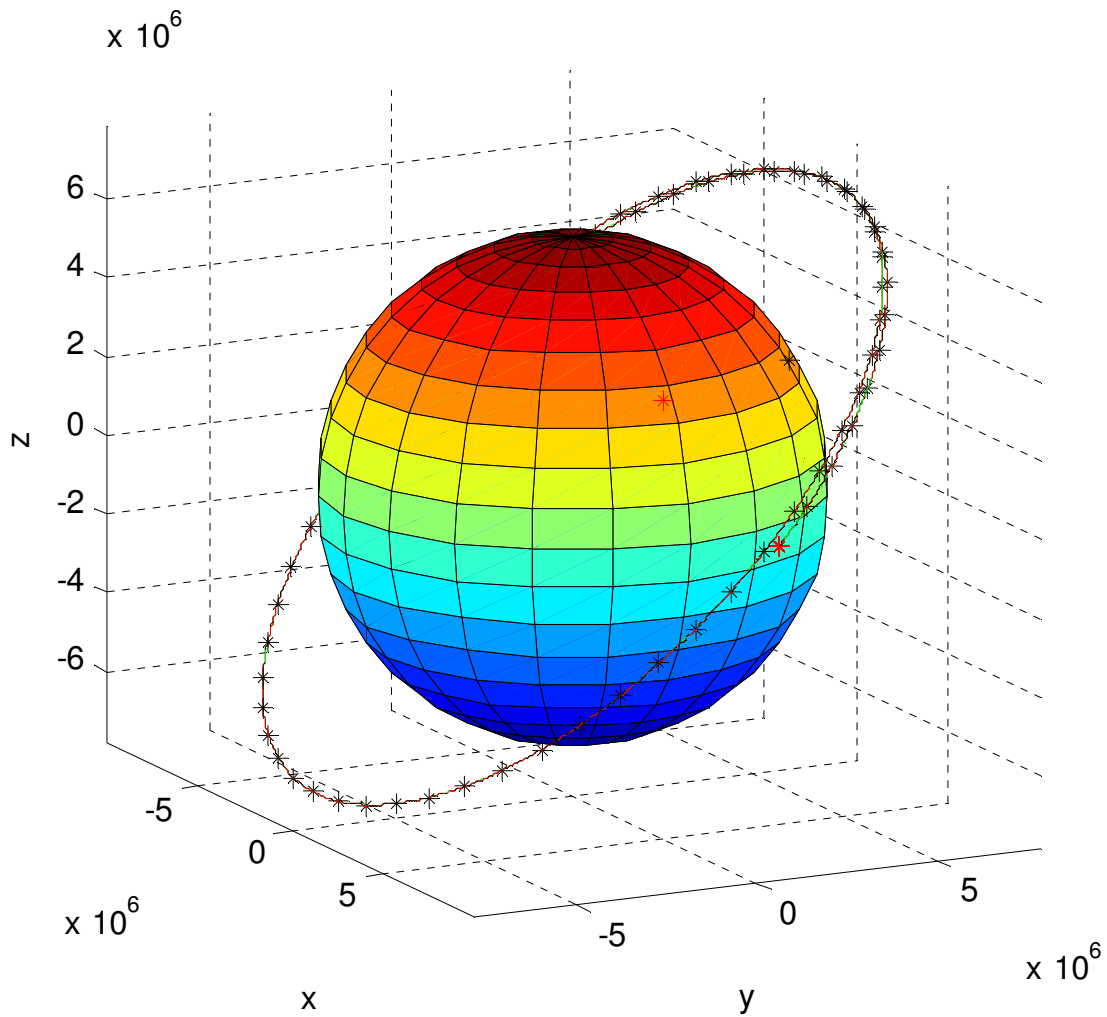


Figure 3: Host and chaser satellites in orbit about a spherical Earth

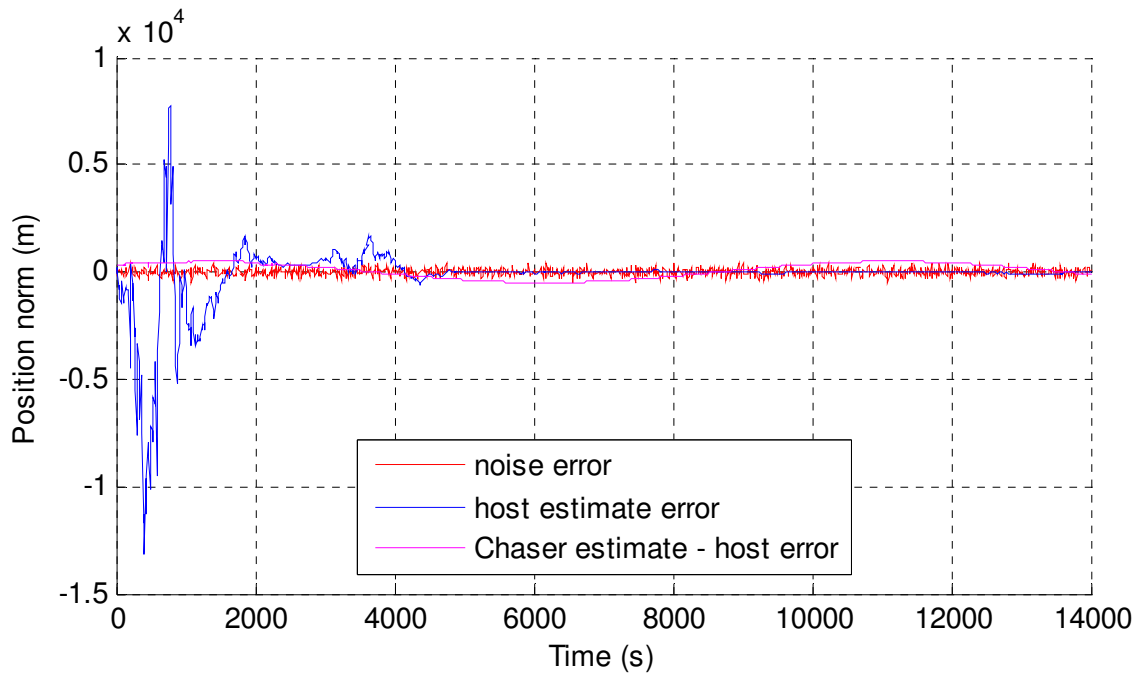


Figure 4: Error between the noisy, estimated, and host states relative to the true chaser state

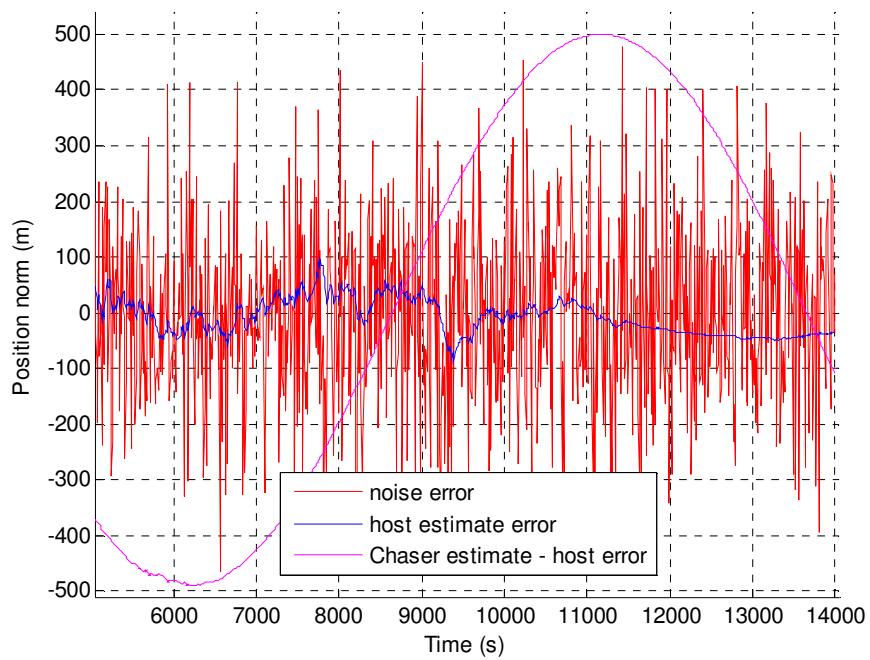


Figure 5: Host noise and estimate error for last 9000 seconds of simulation

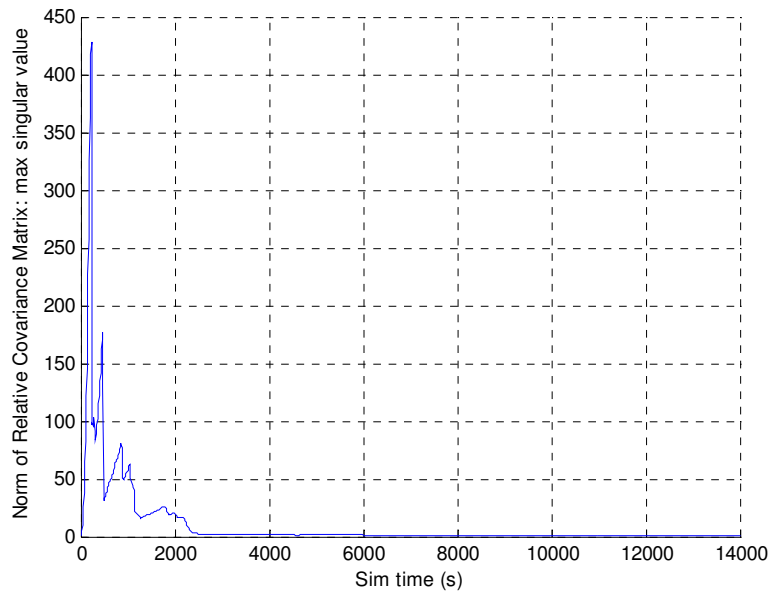


Figure 6: Norm of relative covariance matrix over duration of simulation

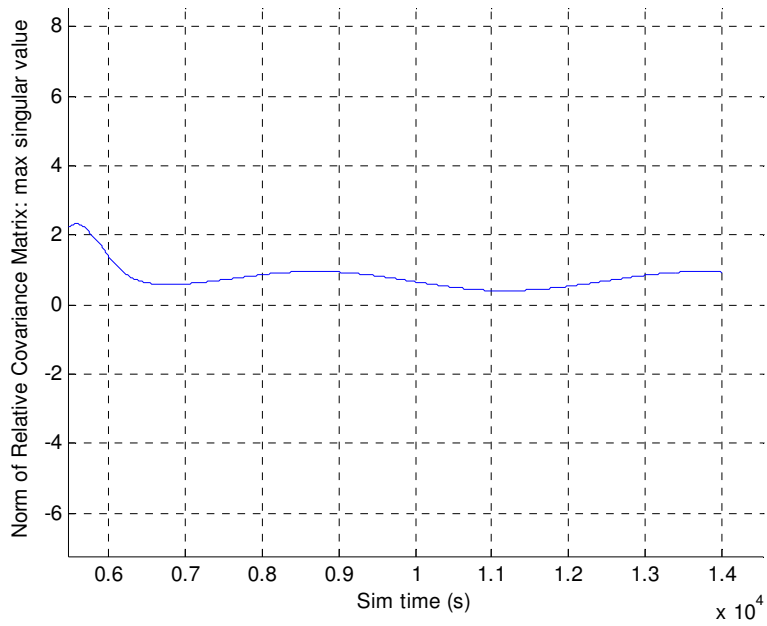


Figure 7: Norm of relative covariance matrix for last 8000 seconds of simulation