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RELATIVE STATE ESTIMATION FOR SPACECRAFT FORMATION FLIGHT

Abstract

Applications of groups of spacecraft orbiting in close distances from each other are on the rise, because formations of smaller spacecraft offer potential for improved affordability, adaptability, and robustness of missions that would traditionally be accomplished by a single large and complex vehicle. The problem of estimating, in real time, the relative position and velocity of two spacecraft flying in proximity of each other is considered. One of the spacecraft, called the chief spacecraft, is assumed to have a known trajectory, whereas the state of the other vehicle, referred to as the deputy spacecraft, relative to the chief is to be estimated. First, Newton's law of gravitation is used to describe the motion of each spacecraft and their relative dynamics. Then, the known absolute state (consisting of the inertial position and velocity) of the chief is used in conjunction with rotation matrices to relate an estimate of the two spacecraft's relative state at any instance to those at the previous time step. A Kalman filter that fuses measurements of the deputy's inertial acceleration and the inter-spacecraft range data is proposed upon constructing a novel linear time-varying system for the estimation model. The acceleration measurements are assumed to be available every 0.1 s via an accelerometer on-board the deputy, while inter-satellite range updates are provided every 10 s by a laser range finder on-board the chief. Lastly, the functionality, performance, and observability of the proposed state estimator are studied via numerical simulations with simulated data (based on a truth model perturbed with random noise), and the effects of the ellipticity of the reference orbit and the presence of external disturbances (namely J2 perturbations caused by Earth's non-spherical shape) are examined. The suggested Kalman filter is shown to work well in a variety of simulation cases, providing an estimate that converges to within ± 10 m and ± 0.5 m/s of the true relative state (assumed to be in the order of 1 km and 100 m/s in each direction). Convergence is achieved within 150 s, even when the initial guess of the estimator is significantly erroneous.