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UPPER STAGE MASS PROPERTY ESTIMATION IN THE PRESENCE OF SLOSHING FLUIDS WITH LOW BOND NUMBERS

Abstract

Estimation of the mass properties, i.e. mass, center of mass (COM), and moment of inertia (MOI), for space vehicles has broad applicability to a wide array of missions. Mass property estimation requires that the spacecraft be modeled as a rigid body while fully accounting for any roto-translational or orbit-attitude coupling. Furthermore, for certain vehicles where relatively large fuel masses slosh in their respective tanks, the estimation scheme utilized in the literature needs to be revisited. This work considers geometric treatment of the system dynamics and estimation in the special Euclidean space (SE(3)) which uses rotation matrices for attitude representation and allows for the design of a single estimation scheme for the system while fully describing the position and attitude of the system and how they evolve in time. The formulation on SE(3) is effective since it handles the coupling between rotational and translational motion while leveraging rotation matrices to represent attitude. This representation does not fall victim to the singularity and non-uniqueness issues inherent to attitude parameterization sets. Also, consideration is paid in this work to sloshing of a low-Bond-number liquid in a second stage undergoing a de-orbit or re-entry burn. In this general scenario, the mass properties are varying in time, meaning that the estimation of these mass properties can be conducted utilizing an (SE(3)-based) Unscented Kalman Filter via system excitation while applying a model to capture the behavior of the sloshing liquid. One of the models under consideration here (among other classical methods, like equivalent-mechanical models) includes development of a Fourier-series approximation of the surface of the liquid in three dimensions within the tank. These approaches to capturing the sloshing behaviors will be leveraged to estimate the mass properties of the vehicle as they vary in time. Estimation of the time-varying mass properties, as well as the estimation of the MOI of the sloshing liquid proposed in this work is novel and can be employed to a variety of situations where sloshing presents non-negligible perturbations or uncertainties in the dynamical model of a vehicle.