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ENHANCING TRAJECTORY RECONSTRUCTION FOR LAUNCH VEHICLES: A CONSIDER MULTIPLICATIVE EXTENDED KALMAN FILTER APPROACH

Abstract

Trajectory reconstruction is of paramount importance in the aerospace industry, especially in the case of launch vehicles (LVs), where safety and cost constraints limit the feasibility of experimental tests under representative operational conditions. Accurately determining the LV position, velocity, and orientation during flight allows engineers to evaluate the LV performance effectively, as deviations from the nominal trajectory offer invaluable insights into the vehicle's aerodynamic characteristics, propulsion system efficiency, and overall flight dynamics.

This paper addresses the challenge of estimating aerodynamic angles and relative-to-air velocity components of LVs during the atmospheric ascent phase. It introduces a Consider Multiplicative Extended Kalman Filter (CMEKF) tailored to manage uncertain parameters and systematic errors in measurement instruments. Unlike prior methods, the CMEKF allows handling a large number of uncertainty sources, possibly not observable, without hindering the observability of other filter states.

The study's broader aim is to furnish a versatile tool that contributes to various research areas within the field, notably uncertainty quantification in LV models. Addressing uncertainties arising from measurement errors, environmental conditions, and modeling assumptions is pivotal, necessitating the development of robust techniques for accurate estimation and propagation of these uncertainties. To this end, this paper adopts a high-fidelity LV model that encompasses various complexities, including flexibility, uncertain aerodynamic coefficients, and propulsion characteristics. The study explores various sets of measurement instruments to assess their effectiveness in augmenting estimation accuracy.

Monte Carlo analyses are carried out to demonstrate the efficacy and consistency of the proposed approach when accounting for uncertainties inherent in both aerodynamic coefficients and thrust magnitude. As a major improvement with respect to similar works in the literature, the proposed approach also provides estimation of the deviations of atmospheric states from the adopted model as a specific feature of the filter, rather than incorporating them as uncertainties, along with the determination of corrections for the aero-propulsive coefficients, the uncertainty of which strongly influences the behavior and fidelity of LV simulation models. Moreover, a smoothing technique is discussed which makes use of both forward and backward passages so as to provide improved estimates in post-flight analysis, especially the estimates in the earliest part of the flight, which may suffer from initialization errors.