51st IAF STUDENT CONFERENCE (E2)
Student Conference - Part 1 (1)

Author: Mr. Federico Gettatelli
Sapienza University of Rome, Italy, gettatelli.1786298@studenti.uniroma1.it

Dr. Boris Benedikter
Sapienza University of Rome, Italy, boris.benedikter@uniroma1.it
Dr. Alessandro Zavoli
Sapienza University of Rome, Italy, alessandro.zavoli@uniroma1.it

STOCHASTIC CONTROL OF THE APOGEE ALTITUDE OF AN ASCENDING MODEL ROCKET

Abstract

This paper investigates the problem of controlling the apogee altitude of a model rocket subject to various uncertainties, such as atmospheric disturbances, system parameter uncertainties, and measurement errors, using a stochastic approach. Thanks to their simplicity and cost-effectiveness, model rockets are excellent testbeds for evaluating novel technologies for small launch systems.

In the considered problem, after the burnout of the solid-fuel rocket motor, the vehicle can adjust its speed only by regulating the extension of the air brakes, which control the longitudinal drag force. The objective is to design a closed-loop control law to effectively steer the rocket towards a target apogee altitude with minimal overshoot, despite the inherent uncertainties in the system.

Uncertainties must be accounted for in the design of the control system, as the limited computational resources onboard the rocket make impractical the use of computational algorithms, such as model predictive control (MPC), which provide robustness via iteratively updating the control signal based on real-time measurements. Other methods, such as dynamic programming, are also overlooked, as they may require a prohibitive computational effort even for off-board hardware because of the curse of dimensionality.

Motivated by recent advances in stochastic optimal control, a covariance control approach is pursued. Covariance control is a stochastic optimal control framework to design a closed-loop control policy that minimizes a given cost function and is robust to the considered uncertainties. Specifically, we parameterize the air brake extension law as a feedforward signal and an additive linear state-feedback term to formulate an optimal covariance control problem that concurrently optimizes the feedforward signal and the feedback gains, while minimizing the apogee altitude variance. The associated stochastic optimal control problem is recast as a sequence of deterministic convex optimization problems by replacing random variables with their mean and variance, exploiting convenient lossless relaxations, and successively linearizing the nonconvex constraints. The solution is stored in the onboard memory as a look-up control table.

Numerical results are presented for a study case involving a model rocket for the European Rocketry Challenge (EuRoC 2024). Specifically, Monte Carlo simulations demonstrate the effectiveness of the attained control policy in regulating the apogee altitude of the rocket despite the uncertainty of the burnout conditions and the in-flight perturbations. Finally, we compare the performance of the proposed stochastic control system with an MPC-based algorithm, also discussing the maximum MPC update frequency achievable by model rocket hardware.