AI Impact & Autonomy on Space Exploration (14)
AI Impact & Autonomy on Space Exploration - Session 4 (4)

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PRE-FLIGHT ONBOARD ALGORITHM VALIDATION THROUGH SIMULATION OPTIMIZATION AND DEEP METRIC LEARNING

Abstract

Aerospace vehicle control algorithms are typically designed using reduced fidelity models. The impact of complex nonlinear system parameters on control performance must be assessed through comprehensive ground simulations. When faced with a large number of significant but uncertain system parameters manual test case design can overlook critical parameter combinations. This risk is substantial when sensitive parameter perturbation combinations are not located at the extreme limits. Through simulation optimization we propose a method to explore large parameter spaces and autonomously identify perturbation levels that lead to unexpected control performance. We further analyse the sensitivity of the system to these parameters through decision trees.

An initial set of simulations are carried out to establish an expected performance baseline. The monitored parameters from these simulations are used to train a latent vector representation through contrastive learning. We propose an algorithm that identifies diverse performance outliers from among the sampled simulations. These outliers are designated as 'leaders' for subsequent simulation optimization. The objective function is defined as the minimization of the similarity between the performance latent vector encoding and the latent vectors of the baseline set. To promote exploration of the parameter space, all solutions in the population are repelled from each other as well.

This automated testing framework allows for the identification of parameters that cause unexpected performance without explicit definition of performance thresholds. By partitioning the population of candidate solutions among diverse 'leaders', the algorithm explores multiple modes of operation simultaneously. This generates test case definitions that comprehensively evaluate the robustness of the designed control algorithms.

We first demonstrate the algorithm on a second order system with manufactured modes of instability. This test verifies the capability of the algorithm to identify test cases in a controlled environment. The method is initially applied to an autonomous winged landing experiment. Uncertainties in the aerodynamic parameters and the initial conditions were optimized for outlying touchdown conditions and control performance. Subsequently, we apply the method to a retro-propulsive lunar landing missions to perturb propulsion and navigation parameters.