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A SHRINKING HORIZON MODEL PREDICTIVE CONTROL FOR LANDING OF REUSABLE LAUNCH VEHICLES

Abstract

The recent advancements of the onboard computational capabilities enable the deployment of GNC algorithms to perform autonomous decisions and complex operations in the final stages of a landing manoeuvre of Reusable Launch Vehicles (RLV). In most cases, such algorithms embed model predictive schemes to optimize during flight by offering a wider versatility compared to classical schemes and the capabilities of identifying potential future behaviours and risks for the mission. Applications such as the vertical landing of reusable launchers (i.e. SpaceX Falcon 9, and Blue Origin New Shepard) and planetary landers (NASA Perseverance) are currently operating or under development by considering the potential benefits of such a technology.

A shrinking horizon Model Predictive Control (MPC) is proposed for the guidance and control of RLV during powered descent phases. Standard MPC schemes use receding horizons where the optimal controls are calculated during constant time-length intervals. The direct implementation of such schemes leads to a hovering-like behaviour of the vehicle, which will never reach the landing platform as the final time of landing is always postponed at each iteration step. The solution proposed in this paper consists on implementing an MPC algorithm that calculates and updates the optimal thrust profile along time-dependent decreasing horizons. The algorithm updates and adapts the time-length of the receding horizon as a function of a time-scaling factor and the time that has passed since the last MPC iteration. It introduces a new concept called terminal horizon, which determines the maximum time in which the RLV must be landed. The optimal solutions are found through convex optimisation algorithms. Numerical simulations and results show an enhanced performance of the guidance scheme and validate the idea that a decreasing horizon is more suitable than a receding one in a powered descent scenario. Monte Carlo and Parametric analyses are performed to assess the performance of the proposed algorithm in a landing test case scenario. This simulated case considers the disturbances caused by Earth's atmosphere drag force in interaction with a descending first stage of SpaceX Falcon 9 rocket. This study demonstrates the applicability of the proposed MPC technique identifying feasibility boundaries for tuning the MPC parameters and determining the range of initial conditions that allow for a successful landing.