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Title

Nonlinear Dynamic Inversion Autopilot Design for Thrust Vector and Aerodynamic Controlled Aerial Vehicles

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Abstract

Due to technological developments, both agility and stability are expected from aerial vehicles in highly nonlinear environments with successful flight missions over large flight envelopes. Since the performance requirements of such systems become more challenging, different design features are added to systems; for instance, thrust vector control (TVC) in addition to aerodynamic control (AC) to increase maneuverability and stability under certain conditions. In addition to the developments in the system design, improvements in the control techniques are required at the same time to make full use of the vehicles. For instance, to increase the flight performance and meanwhile maintaining stability, nonlinear control methods are preferable for highly maneuverable systems. Among nonlinear control strategies, nonlinear feedback linearization (NFL) is a powerful technique. It allows improving the system's capabilities by shaping the poles and zeros of the closed-loop system in a mapped domain with linear tools. Nonlinear Dynamic Inversion (NDI), which is a subclass of NFL, used in many applications. Some examples of NDI with AC are already studied in [1], [2], and [3]. A system with only TVC is discussed in [4] concerning this problem via redefining the acceleration according to wind frame to apply the NDI. Also note that, accurate aerodynamic angle information required in [4], which may not be possible to provide.

There are few studies for control in boost phase, where the time-variation of the states are extreme due to the speed change in a short duration, especially involving nonlinear methods. Moreover, there is not an NDI study concerning simultaneous TVC and AC in this phase to the knowledge of authors. In this study, NDI autopilots for roll angle and accelerations in the pitch and yaw channels are designed for a system that has AC fins and jet vanes for TVC, which are used simultaneously. The two-loop cascaded autopilot structure is designed, where the inner loop is composed of the angular rate dynamics, which is faster than the outer loop, the acceleration loop. The Proportional-Integral (PI) controllers with second-order reference models are preferred to increase the stability under uncertainties and disturbances. A physically inspired output redefinition at the center of percussion is adapted from [5] to overcome the non-minimum phase characteristic of the system and guarantee internal dynamics stability. The autopilot performances are demonstrated with a high-fidelity mathematical model, and it is compared with ad-hoc scheduled linear autopilots designed as given in [6]. Moreover, a stability analysis is carried out in the presence of high levels of uncertainties. Under such uncertainties and a highly coupled set of commands, the autopilot preserves stability and tracks the reference commands successfully. Moreover, a guided scenario is inspected via implementing the inertial measurement model including the sensor uncertainties, and with the lack of information such as angle of attack and side slip. Even in such challenging conditions, the performance of the autopilot is satisfactory. Thus, this study presents promising results for such an agile system, which has both TVC and AC in the boost phase, while filling the gap in the literature.

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