

Examination of Unified Control Incorporating Generalized Control Allocation

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Hybrid vehicles which combine vertical take off and landing with cruise configurations pose a unique challenge for control design and implementation. For this class of vehicle, successful control designs have historically broken the flight envelope into phases of flight and modified the control approach for each phase. This research approaches control in a unified way across the entire envelope utilizing a robust optimal design which provides effector weighting then implemented in a generalized Affine Generalized Inverse control allocation algorithm. System performance for a Lift plus Cruise class vehicle is presented.

I. Introduction

The proliferation of unconventional aircraft designs emphasizes shortening the design cycle and reducing development costs requiring simplified control approaches which are robust, require minimal modeling while still fully exploiting the unique capabilities of the unconventional configurations. Hybrid vehicles (e.g. Vertical Take-off and Landing) are one such class of vehicle that present a substantial control design problem across a large flight regime from hover to cruise flight. Moreover, ubiquitous use of hybrid vehicles in the future implies a greater need for autonomous control due to an expected decrease in vehicle operator experience, and an increase in the number of effectors and complexity. Typical control approaches for hybrid vehicles establish several control modes based on flight conditions with mode specific control approaches using particular effector combinations. In this work, unified control design enables a single control mode that blends optimal control with control allocation to provide control throughout the entire flight envelope without prescribed effector sets. This approach blends several design strategies into a higher level set of control variables that can be easily integrated into a pilot in the loop, fully auto-trajectory tracking, or some combination thereof.

This research highlights three major challenges to developing a unified approach for transitioning from hover to forward flight and vice versa. First, is the number of actuators (e.g. redundancy) and how their individual effectiveness changes over the flight envelope. For example, a tilt wing where ailerons in the propeller slipstream produce a yaw moment in hover but produce a roll moment in cruise. The second, is addressing the change in system relative degree,

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that is the relationship between available actuator input to the derivative of the control variable. For example, in hovering flight vertical velocity is regulated by controlling the speed of the rotors which directly translates to thrust. However, in wing borne flight, the vertical velocity is indirectly regulated using the angle of attack, which is related to pitch which is controlled using a pitch acceleration due to an elevator deflection. The third challenge is ensuring the choice of control variables provide control throughout the entire flight envelope. Traditional pilot in the loop flight control systems focus on the feel and response of the aircraft to the pilot inputs, and how the aircraft is flown is still largely controlled by the pilot. In order for VTOL aircraft to be flown without requiring extensive experience in each configuration, it is necessary to use control variables that raise the level from which the pilot operates the vehicle. For instance, in hover instead of the pilot commanding a pitch rate to accelerate forward she would command the desired forward speed and control system would handle how the aircraft accelerates to the commanded forward speed. As the aircraft traverses through the flight envelope it is the control system and not the pilot that handles how an acceleration is generated. This approach to aircraft flight control design, doesn't require the pilot to keep the aircraft inside the safe flight envelope, but instead the aircraft protects the pilot from flying outside the safe operating envelope.

To address the challenges described above we present a robust control design approach that unifies the design process over the complete flight envelope. This is accomplished by breaking the problem into performance and actuation components where optimization methods are used to dictate both the response of the aircraft and how that response is achieved through the available actuators. The two optimization problems are combined to form a single system where established singular value practices for multiple input multiple output(MIMO) systems can be used to determine the robustness of the synthesized controller. The changing relative degree is handled through the use of virtual controls, where the particular system states are included as control inputs to achieve the desired accelerations when direct actuation is not available. Finally the control variables are chosen such that the desired action, e.g., a vertical climb or heading change are incorporated into reference input so as to raise the level at which the aircraft is controlled by the pilot.

One of the main features of this work is the separation of the control design from the control implementation. This is accomplished by abstracting the control design as previously discussed and coupling this with a new generalized control allocation algorithm. In this research, control allocation uses an expanded Affine Generalized Inverse (AGI) algorithm which was expanded to include arbitrary positive (semi) definite effector weighting, incorporation of a preferred control, and redundant affine control effectors subject to arbitrary (e.g. one-sided) effector position and/or rate limitations. These algorithm enhancements, coupled with use of singular value decomposition for pseudo-inverse computation, enable the AGI algorithm to provide optimal allocation for linearized vehicle states throughout the flight envelope.

This article is organized in the following way: Section II describes preliminaries and outlines the unified control approach. Section III outlines the integration of control allocation and delineates the expansion of the Affine Generalized Inverse algorithm. Next, Section IV presents an analysis of unified control performance for a Lift plus Cruise hybrid vehicle. The conclusions in Section V complete this article.