Adaptive Flight Control for Aircraft Safety Enhancements
Nhan Nguyen, Irene Gregory, Suresh Joshi

Approximate Stability Margin Analysis of Hybrid Direct-Indirect Adaptive Control

Motivation
Despite 5 decades of research, adaptive control still cannot gain acceptance in safety-critical control systems. Challenges include:
• Complex nonlinear behaviors vs. well-understood linear systems
• Lyapunov theory cannot predict boundedness in presence of unmodeled dynamics
• Metrics for stability and performance not yet available
• No guidance on adaptive gain selection for trade-off between performance and robustness
Certification of adaptive control is a major V&V hurdle to overcome

Technical Approach
• Hybrid (composite) direct-indirect adaptive control provides a flexible framework
  – Indirect adaptation via recursive least-squares (RLS) parameter estimation
  – Direct adaptation with lower adaptive gain to improve robustness

Objective
New direct adaptive control methods are being developed for systems with unknown actuator failures:
• Theoretically guaranteed stability and tracking performance

Technical Challenges
• Mathematical modeling, formulation, and analytical framework development
• Accommodation of actuator failures, disturbances, model uncertainties, actuator saturation

Solution
Adaptive control laws for handling actuator failures:
• State tracking
  – State feedback - low complexity; most assumptions
  – State feedback - high complexity; fewer assumptions
Output tracking
  – Output feedback - highest complexity; fewest assumptions

Example Application – GTM (Joshi, Khong)
• One of two elevators locks in unknown position at t = 10 sec
• Remaining operational elevator seamlessly takes over for failed elevator

Conclusions
• Direct MRAC can compensate for unknown actuator failures:
  – Signal boundedness and asymptotic tracking
  – State or output tracking using state feedback has manageable level of complexity

Direct Adaptive Control With Unknown Actuator Failures

Technical Approach
Direct model reference adaptive control (MRAC):
Formulations with increasing complexity and decreasing assumptions
• Actuator failures of unknown magnitude and time of occurrence
• Failure values j0, j1, and failure time t*, pattern (which actuators have failed) are unknown

Example Application – GTM (Joshi, Khong)
• One of two elevators locks in unknown position at t = 2 sec
• Square wave elevator command applied at t = 10 sec
• Remaining operational elevator seamlessly takes over for failed elevator

Conclusions
• Direct MRAC can compensate for unknown actuator failures:
  – Signal boundedness and asymptotic tracking
  – State or output tracking using state feedback has manageable level of complexity

Adaptive Control with Adaptive Pilot Element: Stability and Performance Implications

Motivation
Different adaptive control approaches on different platforms exhibited unpredicted interactions with pilot-in-the-loop flight tests. Adaptive controller will have full control authority
These combined factors have significant implications for closed loop system stability and performance as well as present potentially significant V&V challenge

Technical Approach (Trujillo, Morelli, Gregory)
Mathematically define the pilot as an adaptive controller

For system stability and performance analysis, model the pilot as an adaptive controller; therefore, analyze a system consisting of two adaptive controllers of potentially different architectures. In addition, this analysis will provide:
• Design requirements on adaptive controller to compliment pilot’s actions
• Predicted analytical bounds on pilot-in-the-loop task specific performance

Implications
• Analytically evaluate stability and performance of a closed-loop system with an adaptive controller; therefore, analyze a system consisting of two adaptive controllers of potentially different architectures.
• Contribute to functional allocation between pilot and adaptive control schemes as well as pilot’s situational awareness of system’s capabilities