CLOSING THE CERTIFICATION GAPS IN AIRCRAFT ATTITUDE HIGHER ORDER SLIDING MODE CONTROL

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Overview
The challenge of aircraft flight control is in addressing the model uncertainties and external disturbances. The nonlinear Higher Order Sliding Mode (HOSM) controllers are known for their robustness/insensitivity to matched bounded external disturbances/uncertainties. However, the HOSM controllers must be certified prior to be implemented in aircraft flight control system. Phase Margin (PM) and Gain Margin (GM) are the classical characteristics used for the linear control systems certification to quantify their robustness to un-modeled dynamics. There are certain standards imposed on PM and GM for the controller to be certified for controlling air space vehicles. In this research work, the conventional control system certification approach based on phase and gain margins are extended to nonlinear HOSM controllers. The proposed Practical Stability Phase Margin (PSPM) and Practical Stability Gain Margin (PSGM) are used to quantify the HOSM control system robustness to un-modeled dynamics. The tools/algorithms to identify PSPM and PSGM are developed using Describing Function-Harmonic Balance method. Theoretical developments are illustrated and validated on a case study of F-16 aircraft attitude control.

1. Problem formulation
Consider the following model of an F-16 aircraft:
\[ \dot{x} = f(x, u, \epsilon) + g(x, y, \epsilon) \],
where \( x = [p, q, r, \phi, \theta, \psi]^T \) is a column vector of roll, attack and sideslip angles; \( y = [p, q, r] \) is a column vector of roll, attack and sideslip angular rates; \( \epsilon = [\delta_e, \delta_a, \delta_r]^T \) is a column vector of aileron, elevator and rudder deflections; the symbols of the form \( \delta \) are unknown bounded smooth perturbations due to battle damages, failures and model uncertainties; \( |\delta| \leq 0.37 \text{ rad} \). \( v = a, e, r; u \in R^3 \) is a control vector containing actuator inputs.

Task 1: Tracking errors: \( e_a = x_a - x_0 \rightarrow 0 \) in finite-time.
Task 2: Introduce robustness metrics for designed HOSM.

2. Aircraft HOSM control design
Sliding variables: \( s_x = \dot{x}_s + c \epsilon \), \( c \in R^3 > 0 \).
For the given system,
\[ x = F(x, \epsilon) + \theta + F'(x, y, \theta) \]
where \( \theta = y \alpha \) and \( \gamma \) represents a constant value.
Now, \( \dot{\theta} = \dot{\epsilon}_x + c \dot{\epsilon}_a = \dot{d}_1 + \theta + d \), where \( d_1 \) and \( d \) represent known and unknown terms respectively; \( |d| \leq \text{constant L} \).
Therefore,
\[ \dot{\theta} = -d_1 + \theta + \text{constant} \]
where \( \theta \) is given by HOSM control law.

3. Simulation results

4. Discussion
The prime contributions of this research are as follows:
- Stability margins (PM and GM) are extended to practical stability margins (PSPM and PSGM) to quantify the aircraft HOSM control system to un-modeled dynamics presiding the tool for HOSM control certification.
- Proposed methodologies are demonstrated on a case study of controlling the attitude of F16 aircraft.

References