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Switching Control Strategies for Aircraft Lateral Dynamics

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Abstract— Due to the rapid growth of aircraft systems in the space, the implementation of a more optimized controller for aircraft dynamics control while the system is corrupted by sounds is quite a competitive position at the moment. When transitioning from one mode to other causes significant flight-critical differences in the aircraft dynamics, multi-mode switching between controllers corresponding to distinct modes of operation is required from the perspective of flight control design. It was demonstrated that a wide range of switching control techniques may be generated logically from the fundamental framework, proving the applicability of the suggested strategy. Using the MATLAB/SIMULINK platform, the switching control techniques presented in this research are tested for the longitudinal dynamics of aircraft systems.

Index Terms— LQR, LQG, Fuzzy Logic Controller (FLC), PID.

Nomenclature:
γ- Path angle
θ -Pitch angle
α -Angle of attack
Θ -Roll angle
β -Sideslip angle
q -Pitch rate
U_0- Longitudinal velocity
m- Aircraft mass
δe- Elevator deflection
δr -Rudder deflection
δa- Aileron deflection

1. Introduction

To increase system performance, and assure safe operation in the event that a component fails in any control structure, accounts for environmental conditions, etc., switching between two feedback control structures is a critical component in the current scenario of aircraft systems. The impact of the aerospace and aircraft industries on the worldwide economy and modern society is very strong. As a result, engineering research and development technologies are still being led by the aerospace sector. Improved Guidance, Navigation & Control of the flying systems face a number of challenges, including improved flight performance, self-defence, and prolonged structure life. Recent advances in control engineering, signal processing, and computer sciences have the potential to address these problems.

Technologies for fault tolerant control, fault tolerant guidance, and innovative and viable fault detection and diagnosis that will increase spacecraft availability and safety present significant new challenges, ranging from pre-design and design stages for upcoming and new programs to improvement of the performance for in-service flying systems.

2. Aircraft Lateral Dynamics

The state space form for lateral dynamics is as follows:

$$\dot{x}(t) = Ax(t) + Bu(t)$$

$$x = \begin{bmatrix} \Delta\beta \\ \Delta P \\ \Delta r \\ \Delta\theta \end{bmatrix} \quad u = \begin{bmatrix} \Delta\delta_a \\ \Delta\delta_a \end{bmatrix}$$

$$A = \begin{bmatrix} Y\beta/U0 & Yp/U0 & -(1-\frac{Yr}{U0}) & gcos\theta 0/U0 \\ L\beta & Lp & Lr & 0 \\ N\beta & Np & Nr & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$$B = \begin{bmatrix} Y\delta r/U0 & Y\delta a/U0 \\ L\delta r & L\delta a \\ N\delta r & N\delta a \\ 0 & 0 \end{bmatrix}$$

$$C = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Where,

δa, δr: aileron and rudder deflection

β, Θ: sideslip and roll angle

P, r : roll and yaw rate

The lateral dynamics stability requirements are listed in Table 1.1 (Vishnu G. Nair and Dilip M. V et al. 2012). These requirements must be met in order for this chapter to be used.

Table1.1: Derivative Stability of Lateral Dynamics

Quantity	Yaw Force Derivatives	Yaw Moment Derivatives	Rolling Moment Derivatives
Slide Slip Angle	Y_β=-44.665	N_β=4.549	L_β=-15.969
Rolling Rate	Y_P =0	N_β=4.549	L_P =-8.395
Yawing Rate	Yr=0	Nr=-0.76	Lr=2.19
Rudder Deflection	$Y_{\delta r}$=12.433	$N_{\delta r}$=-4.613	$L_{\delta r}$=23.09

The state space matrix is replaced with the numerical values in the preceding table, and the outcome is as follows:

$$A = \begin{bmatrix} -0.254 & 0 & -1 & 0.183 \\ -15.969 & -8.395 & 2.19 & 0 \\ 4.549 & -0.349 & -0.76 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$

$$B = [B\delta r] = \begin{bmatrix} 0 \\ 23.09 \\ -4.613 \\ 0 \end{bmatrix}$$

3. Model Aircraft Switching Control Strategy Design

The experiment in this section makes use of the lateral dynamics of the aircraft system.The following describes a switched-linear system model:

$\dot{x}(t)$= Aσ(t)x(t)

The σ(t) switching signal indicates that,

if, σ(t) = 1 then $\dot{x}(t)$ = A1x(t)

if, σ(t) = 2 then $\dot{x}(t)$ =A2x(t)

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For the sake of clarity and thoroughness, the three switching control methods are once again illustrated in the following section. It is shown as follows:

Switching Control Algorithm -I

An illustration of the switching control method I that can be used to discover the switching matrix S is as follows: [5]

if $x'Sx \leq 0$ then $\dot{x}(t) = (A-BK1)x(t)$

if $x'Sx \leq 0$ then $\dot{x}(t) = (A-BK2)x(t)$

1. constructing A2 as a potential unstable subsystem while designing A1 to be asymptotically stable.
2. Using the algebraic Lyapunov Equation, solve the problem. : $AT_1^T T0 + T0A1 = -C^T C$.
3. Given the switching matrix S, calculate : $S = -(AT_2^T 0 + T0A2 + C^T C)$.

B. Switching Control Algorithm II

The following is the switching control algorithm II [5]:

$\dot{x}(t) = A\sigma(t)x(t)$

Where,

$\sigma(t) = \{ i, \text{ if } x(t) \in \Omega i$

$\sigma(t) = \{ j, \text{ if } x(t) /\in \Omega i$

C. Switching Control Algorithm III

The switching boundary vectors F1 & F2 with this switching control technique are designed as follows [7, 8]:

$x' F'_1 F_2 x > 0 \; \dot{x}(t) = (A-BK\alpha)x(t)$

$x' F'_1 F_2 x \leq 0 \; \dot{x}(t) = (A-BK\beta)x(t)$

1. 1.Find an alternative controller K that has n-1 real stable eigenvalues in a closed loop as a starting point.
2. 2. The next step is to select a primary controller K from the (A+BK) closed loop eigenvalues so that it has n2 common (A+BK1) eigenvalues and the remaining eigenvalues are complex.
3. To create F1, multiply the $(A+BK_\beta)$ left side eigen value polynomials, and then choose the enlarged polynomial coefficients in ascending powers of s.
4. 4.The polynomial that is subtracted when creating the vector F1 (right side eigen value) with additional (n-2) left eigen values by choosing $\mu < 0$ is multiplied with other (n2) left eigen values to create $F2 = [F1 + \mu\omega 2]$.

4. Experimental design set up

Both scenarios were subjected to the experimental design for this section of the paper, and the outcomes are outlined below:

1. Case I : For the lateral dynamic model of an airplane, the two optimum feedback controllers, K1 and K2, were created utilizing the control input rudder deflection (δr). To switch between the two independent feedback controllers (K1 & K2), the switching control algorithms I & II are implemented along with the necessary adjustments. The results of applying the best LQR tool yield the following numerical values for K1, K2:

K1 = [0.2096 0.6711 −0.6348 1.1047]

K2 = [1.6591 2.5349 −2.1856 3.5090]

2. Case II: The diesel engine model is used in this scenario to show how switching control algorithm III may be used to stabilize between stable and unstable controllers. The optimized and non-optimized feedback controller gains (Kα & Kβ), as well as the switching boundary vectors F1 & F2, can be derived using the following expressions:

Kα =[0.2096 0.6711 0.6348 1.1047]

Kβ = [−0.7823 −0.2832 0.0606 −0.0783]
F1 = [13.5906 5.5159 2.9253]
F2 = [025.1812 5.8505]

The simulation results for switching between two feedback optimum controllers employing switching control algorithm I (SW 1) and switching control algorithm II (SW 2) provide a comparison of system responses for the state variables Slip slip angle and Roll rate deviations in Figures 1.1 and 1.2. The response demonstrates that the state variable is the same for both switching control techniques. However, the switching control algorithm-I technique provides a superior response in terms of settling time than switching for the state variable P.

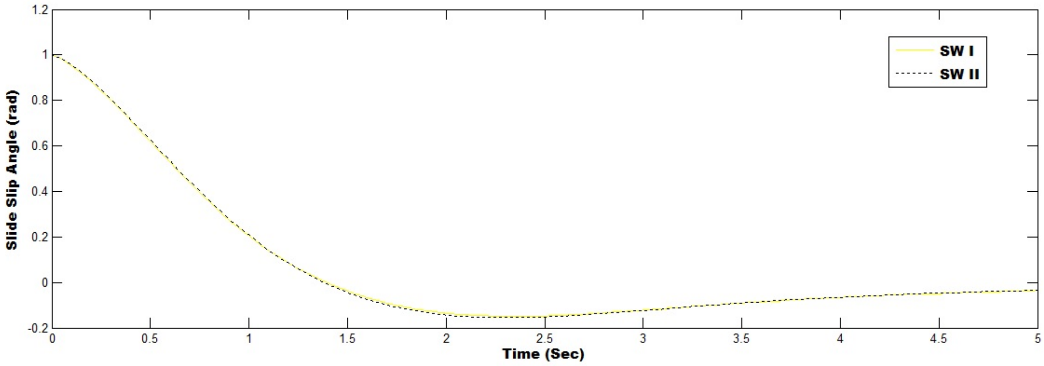

Figure 1.1: Δ P1 response of Case I and Case II

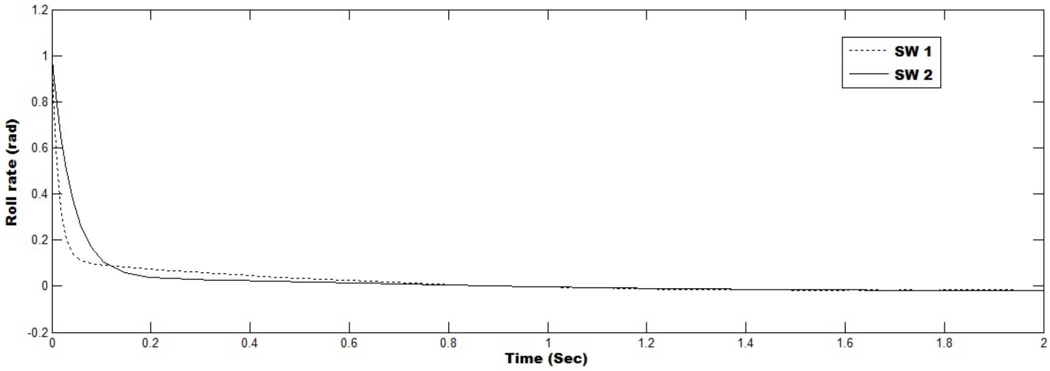

Figure 1.2: δ r1 response of Case II

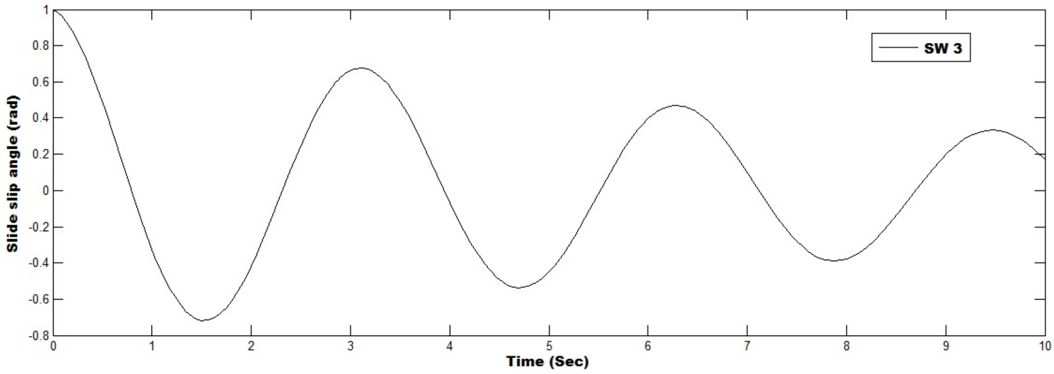

Figure 1.3: ΔP1 response of Case III

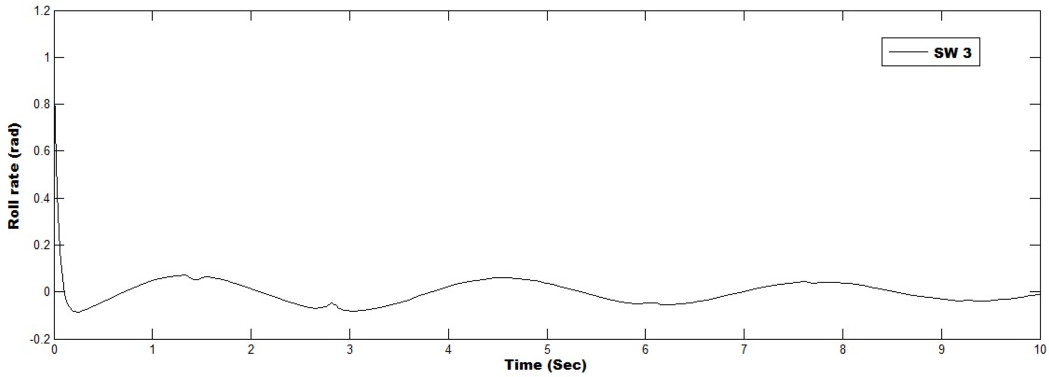

Figure 1.4: δr1 response of Case III

5. CONCLUSION

This work presents the modifications that can be made to two conventional switching control methods to regulate the lateral dynamics of aircraft models using a rudder deflection control input. The two feedback controllers employed in the system are derived using the optimal LQR control theory. The two feedback controllers were obtained by tuning the weighting matrices Q and R, which were utilized to switch in the system. The optimal switching control method for the future is determined by running simulations with the state variables and analysing the responses that arise.

For the two state feedback controllers, an existing intelligent switching stabilization technique is employed with the relevant modifications based on the needs (Stable & Unstable). The goal of this experiment is to show that a system can be maintained in a stable state even if it becomes unstable due to the environment or other outside forces. When the system enters an unstable condition, switching algorithm III will be used to replace the unstable controller with a stable controller. Figures 1.3–1.4 present the outcomes of the examination of the evidence

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