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# Adaptive Fault-Tolerant Control for Aircraft Systems Based on Off-Policy Learning

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## Introduction

Aircraft approach fault-tolerant control has always been a research hotspot. Due to the influence of wind and other factors, aircraft has complex nonlinear dynamics during approach. A new adaptive control strategy is proposed based on the data-driven approach of off-policy learning in this paper, which takes into account the existence of actuator stuck, interruption and loss of effectiveness in aircraft systems, as well as external interference of coupled state vectors. This method avoids the time-consuming system modeling process required for establishing model-based control strategies. At the same time, the influence of external interference constrained by the internal state of the system is overcome, and the stable operation of the system is ensured. Finally, the effectiveness of the method is also proved by simulating the flight dynamics system of the coupling system affected by the actuator failure and the external interference.

## Problem Statement and Preliminaries

Consider a linear continuous system with external disturbance of coupled state vector and actuator fault:

$$\dot{x} = Ax(t) + Bu_c(t) + B_\omega \omega(t) + BG(x)$$

Then considering the possibility of actuator failure, offset, or jamming, we define the actual control input as follows:

$$u_c(t) = \begin{bmatrix} \rho & 0 \\ 0 & \sigma \end{bmatrix} \begin{bmatrix} u(t) \\ u_d(t) \end{bmatrix}$$

$$\rho = diag(\rho_1, \rho_2, \rho_3), \sigma = diag(\sigma_1, \sigma_2, \sigma_3)$$

$$\sigma_j = \begin{cases} 0 \ or \ 1 & \rho_j = 0 \\ 0 & 0 < \rho_j \le 1 \end{cases} (j = 1, 2, 3)$$

Finally, the system can be restructured as the following form:

$$\dot{x} = Ax + B\rho u + B\sigma u_d + BF\omega + BG$$

## Conclusion

This paper proposes an adaptive fault-tolerant control scheme for aircraft systems with coupled state variables, time-varying disturbances, and actuator faults based on off-policy learning. The scheme is designed to be robust and fault-tolerant for general actuator fault models. The proposed strategy can effectively control a carrier-based aircraft in final approach under actuator failures and disturbances. It is expected to be extended and applied to nonlinear systems in order to achieve a broader range of applications.

## Adaptive Control Policy Based on Off-Policy Learning

Adaptive state-feedback system:

$$\dot{x} = Ax(t) + B\rho(K_1(x) + K_2(t) + K_3(t)) + B\sigma u_s(t) + BF\omega(t) + BG(x)$$

and the norm of $G(x)$ is bounded by unknown but estimable constant $h$, i.e., $\|G(x)\| \le h\|x\|$.

Actuator structure:

$$u(t) = K_1(x) + K_2(t) + K_3(t)$$

Error system change law:

$$K_1(x) = -\varepsilon K_t x = -\varepsilon R^{-1} B^T P_t x$$

$$K_2(t) = -\frac{\hat{k}_4^{\,2}}{\|RK_t x\| \hat{k}_4 + \gamma(t)} RK_t x$$

$$K_3(t) = -\frac{1}{2} \hat{k}_5 RK_t x$$

The control law parameters in the actuator structure design are related to the state-feedback gain matrix $K_t$. And the state-feedback gain matrix $K_t$ can be computed using data streams, following the off-policy data-driven approach for linear periodic continuous systems, which does not depend on the initial stabilizing controller and enables online learning based on the collected system input and state.

Then the following conclusions can be obtained by substituting the above control law design into the state feedback system

$$\lim_{t \to \infty} \|x(t)\| = 0$$

## Figures

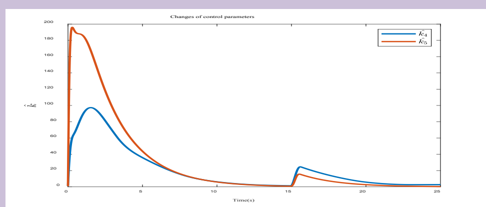


Figure 1. Changes of the controller parameters $\widehat{k}_4$ and $\widehat{k}_5$

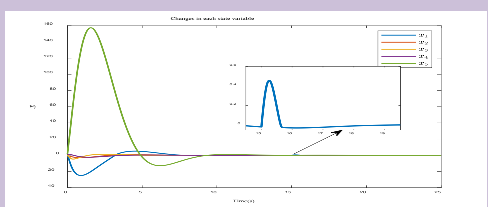


Figure 2. State responses under the actuator failures and disturbances