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Optimized Reconfigurable Modular Flight Control Design using Swarm Intelligence

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Abstract

This paper presents an optimized reconfigurable control design methodology by separating control commands distribution task from flight controller for different types of fault handling. The proposed strategy improves the flight control performance in normal and fault situations. The particle swarm optimization (PSO) based multi-input multi-output (MIMO) linear quadratic regulator (LQR) is used to produce virtual command signals. A modified weighted pseudo-inverse (WPI) based cascaded re-allocation technique is employed for effective implementation of commands to redundant control surfaces in a realistic nonlinear aircraft benchmark model. Control surface fault modelling is performed for the evaluation of optimized reconfiguration based modular flight control strategy. Simulation results show that acceptable fault tolerant control (FTC) performance can be achieved by using swarm intelligence based optimization technique for modular control design.

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Keywords: particle swarm optimization; linear quadratic regulator ;weighted pseudo-inverse;control allocation; non-linear aircraft benchmark model

1. Introduction

Due to the increasing demands and stringent requirements of aircraft performance, safety and reliability, multiple redundant control surfaces with varying configurations are introduced. Especially, the modern aircraft with fly-by-wire (FBW) technology has more reliable actuating surfaces than conventional configuration with mechanical linkages to control the same three rotational degrees of freedom (roll, pitch and yaw). However, this improved reliability comes with greater cost and computational complexity which requires a separate control command distribution module with optimal base-line controller to shape the closed-loop flight dynamics in the complete flight envelope. This modular approach has gained a lot of attention in practical safety-critical and mission-critical applications [1, 2, 3].

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A modular control design approach has been proposed in this research area, where an optimal controller is designed with the allocation algorithm (see Fig.1). In general, LQR controller state feedback gain matrix is derived using intuitive knowledge or through laborious trial and error. Here, we proposed fast reliable approach based on swarm intelligence for determining best possible parameter values of LQR controller for shaping coupled dynamic response of the aircraft. Through modular approach, a control engineer has got more control commands distribution freedom based on the control surface effectiveness and health condition without modifying the base-line controller parameters.

The challenging problem of commands distribution between large redundant constrained control surfaces requires an on-line, efficient and optimal solution. Several optimization based methods are suggested in research literature for applied control allocation (CA) with varying performance indices like computational requirement, allocation efficiency, constraints handling and design simplicity [4, 9, 10]. Bordignon [7] and Page [9] have discussed the control allocation problem without considering tuned base-line controller and re-allocation in faulty case for flight path control. The optimized allocation of moments, forces and available power is still an active research area in aerospace systems considering mission objective requirements like minimum drag, minimum control surfaces deflection and minimum radar cross-section (RCS) [4, 7, 9].

In this paper, volume of the attainable subset (V_{Π}) of a WPI based control allocation strategy is maximized through PSO and compared with direct control allocation method proposed by Durham [5, 6]. The proposed scheme to optimally design the base-line controller and CA algorithm for a fighter aircraft model with various fault cases is demonstrated in this paper. Considering the simplicity, robustness and reasonable performance, LQR is chosen as a base-line controller with an effective control allocation approach based on pseudo-inverse method [4]. The paper is organized as follows: The detail description of the problem with the control scheme is presented in section 2. PSO algorithm for base-line controller and CA optimization is described in section 3. Matlab/Simulink based simulation development and results are given in Section 4. At the end, conclusions with further research directions are given in Section 5.

2. Problem Formation and Control Scheme

2.1 System description

The linearized dynamics of an aircraft at a trim condition is represented in state-space form as

$$\begin{aligned}\dot{x}(t) &= Ax(t) + Bu(t)\\ y(t) &= Cx(t) + Du(t)\end{aligned} \tag{1}$$

Where, $A \in \Re^{n\times n}$, $B \in \Re^{n\times m}$, $C \in \Re^{p\times n}$ and $D \in \Re^{p\times m}$ are respectively the state, the input control, the output and feed-through matrices, $x \in \Re^{n}$ is the system state vector; $u \in \Re^{m}$ is the control input vector and $y \in \Re^{p}$ is the system output vector to be controlled in an optimal way. Here, feed-through matrix D is a null matrix and all states are measurable and the system is full-state feedback system. Now, for incorporating actuator faults or failures, we introduce a diagonal gain matrix $K \in \Re^{m\times m}$ in Eq. (1).

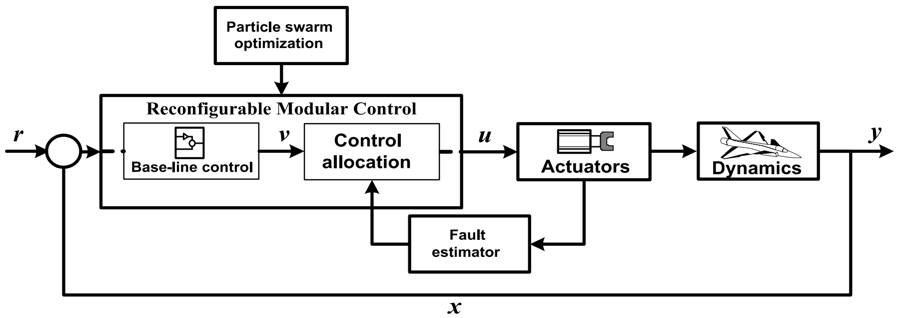

Fig. 1 Structure of optimized reconfigurable flight control system