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# Neural network-based fault detection method for aileron actuator ☆

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ABSTRACT

Fault detection for aileron actuators mainly involves the enhancement of reliability and fault tolerant capability. A fault detection method for aileron actuator under variable conditions is proposed in this study. In the approach, three neural networks are used for fault detection and preliminary fault localization. The first neural network, which is employed as an observer, is established to monitor the aileron actuator and estimate the system output. The second neural network generates the corresponding adaptive threshold synchronously. The last neural network is used as a force motor current observer, and outputs estimated force motor current. Faults are detected by comparing the residual error (the difference value between the actual and estimated output) and the threshold, or comparing the force motor current and the estimated force motor current. In considering of the variable conditions, aerodynamic loads are introduced to the neural network, and the training order spectrums are designed. Finally, the effectiveness of the proposed scheme is demonstrated by a simulation model with different faults.



## 1. Introduction

Aileron Actuators are widely used in the aerospace industry such as flight control system of aircrafts and missiles [1]. Faults of aileron actuators such as internal leakage fault or sensor fault can cause serious degradation in system performance [2]. Therefore, effective detection and isolation of faults in an aileron actuator is vital for enhanced aircraft safety and accomplishment of the intended mission [3]. Detection of faults is essential for initiating maintenance action to prevent total failure of the system [4].

A variety of aileron actuators fault detection studies have been developed theses years [5,6]. For example, Detection of a sensor fault is done with the help of knowledge-based neural network [7]. Gheorghe brought model-based fault detection approached to flight tests, and a Kalman-based solution is given in his study [8]. Liu, Jiang and Zhang proposed sliding mode observer-based fault detection for a flight control system [9]. Jayakumar and Das proposed a scheme of fault detection for flight control system based on Luenberger observer [10]. However, many of these studies are suitable for fault detection under single conditions, and little research take the aerodynamic loads into consideration, while in practice, the system input of aileron actuator is random signal and the aerodynamic loads cannot be ignored [11]. Besides, with these methods, some

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faults, such as hydraulic pump fault, or external leakage fault can hardly be detected. In our previous research [12], bi-step neural network and autoregressive model were used to assess the performance of hydraulic servo system, however, the performance assessment was also conducted under single condition, without aerodynamic loads.

To promote the practicability of fault detection for aileron actuators, in this study, fault detection methods under variable conditions based on neural network are proposed. The detection is realized with a system observer, an adaptive threshold generator and a servo valve force motor current observer, by using system input, system output, aerodynamic loads and force motor current (FMC) of servo valve. The first neural network, acts as the system observer, is used to estimate the aileron actuator output and calculate the residual error. The second neural network, as the adaptive threshold generator, output the adaptive threshold, by comparing the residual error and the adaptive threshold, electronic faults of aileron actuator can be detected. Meanwhile, the FMC observer, also based on neural network, is used to estimate the FMC of servo valve, and the mechanical fault can be detected by comparing the estimated FMC and the actual FMC. Compared with existing methods, the advantages of this method is the efficient synergy between the residual error and adaptive threshold, with adaptive threshold, the method proposed in this study works well under variable conditions, and the detection is more accurate; with the FMC, faults can be localized to some degree. Meanwhile, compared with our previous work [12], more faults (such as external leakage fault, pump fault, etc.) can be detected and localized, and the detection/localization is under variable conditions and variable aerodynamic loads because of the improved algorithm and the new control parameters (FMC), it is more practical in engineering fields.

The structure of this paper is explained as follows. In Section 2, the simulation model of aileron actuator is established. In Section 3, the proposed method is described in detail. In Section 4, the effectiveness of the proposed approaches is demonstrated by using simulation data with different faults, and the results of experiment are presented and discussed.

## 2. Set up of aileron actuator

The closed-loop control system is shown in Fig. 1. The mechanical part of the system is composed of servo valve, cylinder, together with hydraulic pump; the control part of the system consists of PID controller, amplifiers, and sensors. The signals used for fault detection are marked with red balls.

The simulation model is established in combined simulation environment (Matlab Simulink and AMESim), the mechanical parts are simulated with AMESim, and the control parts are established in Matlab Simulink environment [13]. The mechanical parts simulation is based on physical parameters, therefore, the simulation is more accurate. The interface between AMESim and Matlab Simulink is S-Function.

The hydraulic cylinder of aileron actuator simulation model is composed of two piston modules and one leakage/viscous friction module. The leakage/viscous friction module is used for cylinder internal leakage fault injection [14].

The elementary hydraulic properties are shown in Table 1. In this study, the aileron actuator is supposed to work under constant temperature, 40 °C, and the kinematic viscosity decreases with the increase of temperature.

The parameters of pressure source are shown in Table 2, in normal condition, the pressure of the pump is 210 bar.

The parameters of servo valve are shown in Table 3. In normal condition, the flow rate at maximum valve opening is 150 L/min, and the pressure drop is 20 bar.

The parameters of leakage and viscous friction module are shown in Table 4. In normal condition, the clearance diameter is set as 1e−5 mm, and the diameter is increased when internal leakage fault is introduced.

The parameters of piston modules are shown in Table 5. The piston diameter is 90 mm, the rod diameter is 30 mm and the chamber length at zero displacement is 150 mm.

The parameters of displacement sensor are shown in Table 6. The gain for signal output is 1.

The parameters of mass and displacement module are shown in Table 7. This module is used to limit the movement scope of hydraulic cylinder.

The parameters of spring damper are shown in Table 8. This module is used to simulate the damp of aerodynamic loads.

The parameters of flow control valve are shown in Table 9.

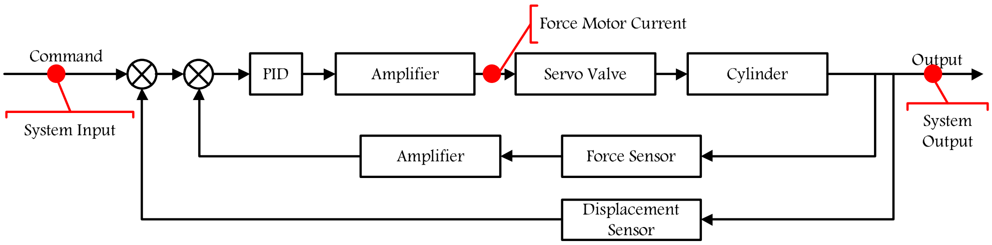


**Fig. 1.** Closed-loop control system of aileron actuator.