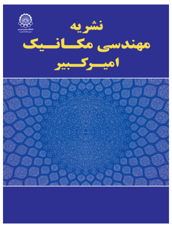

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Design of Fault Tolerant Controller in Flight Control System

O. Sedghi, S. H. Sadati*, J. Krimi

Department of Aerospace Engineering, Malek Ashtar University of Technology, Tehran, Iran

ABSTRACT: Any defect in the flight control system may cause an irreparable problem. Typically, a highly reliable system with human decision-making power is used to prevent or correct such errors in a flying vehicle. A fault tolerant control system is designed to deal with various types of errors that may occur in the system. Fault-tolerant control systems are divided into two main parts. The first part is the error detection and isolation phase and the second part is the control system design phase to overcome the error effects in the system, depending on the type of error and the location of the error, whether the sensor, actuator, or components, the control system must be able to eliminate error effects. In this paper, a neural-adaptive observer is used in the error detection stage, and in the second stage, a control system is designed based on the back-stepping algorithm. Nonlinear six-degree-of-freedom simulation results for an F-18 aircraft model indicate its suitable efficiency in the detection and compensation of fault effects.

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1- Introduction

Measurement errors of sensors and sub-system faults may change the dynamic characteristics of closed-loop systems, and this leads to a decline in system performance. Three types of faults are actuator damage, sensor damage, and parametric faults. Fault phenomena can be categorized as sudden, smooth, or temporal [1]. A fault tolerant system performs three important tasks including detection, isolation, and identification (estimation) of fault.

Bodson and Groszkiewicz [2] proposed a model reference adaptive control having tunable parameters. A mechanism is introduced for tuning the algorithm parameters. The proposed approach is effective for many fundamental faults of the system. Implementing an adaptive model obligates the process output to track a reference model. Dan Ye et.al. [3] designed a robust controller based on the H^∞ minimization norm. H^∞ algorithm is used as an index of fault occurrence in a closed-loop system. In Ref. [4], an active fault tolerant system is designed for a quadrotor based on model predictive control. An extended Kalman filter is also designed for tolerating decreased efficiency of the actuator.

In the current research, error occurrence in sensors and ways for eliminating fault effects is assessed. In this way, for fault identification and detection, an adaptive neural network observer is designed. A fault tolerant control system is designed in two steps: in the first step, utilizing adaptive neural networks and an extended Kalman filter, faults are detected. In the second step, an adaptive controller is designed based on a back-stepping approach which aimed to eliminate fault effects in the system. A complete nonlinear dynamic model of an F-18 airplane during a maneuvering flight is used as the plant.

2- Fault Detection and Control System

As previously mentioned in the introduction section, the proposed approach in this article is a two-step strategy. The block diagram of fault detection and fault control steps is drawn in Fig. 1.

The step after fault detection is identifying the fault location and separating that part from other parts. In the disclosure unit, the nonlinear dynamic model is linearized, and the residual is calculated. Then, by defining a threshold error function, the error may be assessed. Adaptive neural networks and extended Kalman filters are used for fault detection.

The designed control system has two loops: in the outer loop slow states including the angle of attack, side slip angle, and roll angle are controlled. Fast states of angular rates are controlled in the inner loop. Fig. 2 shows a block diagram of the control system. an adaptive controller is designed based

*Corresponding author's email: hsadati@aut.ac.ir

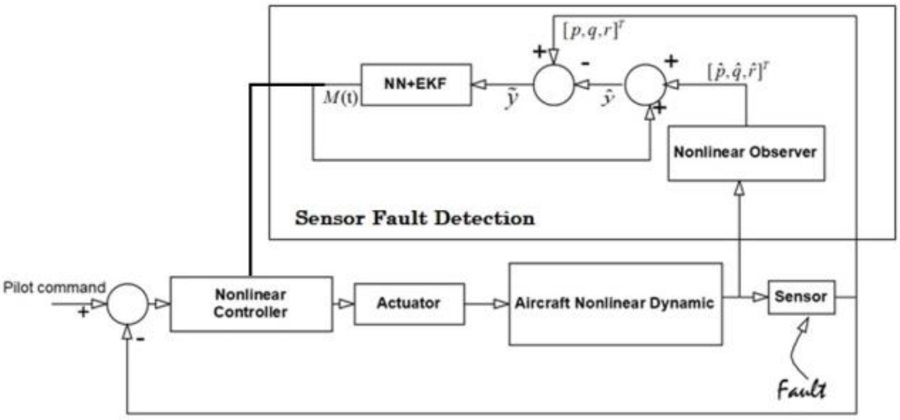

Fig. 1. Block diagram of the proposed algorithm

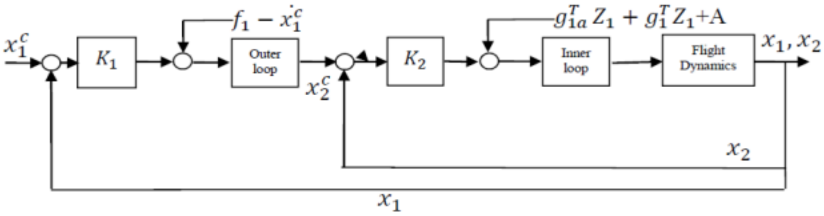

Fig. 2. Block diagram of designed control system

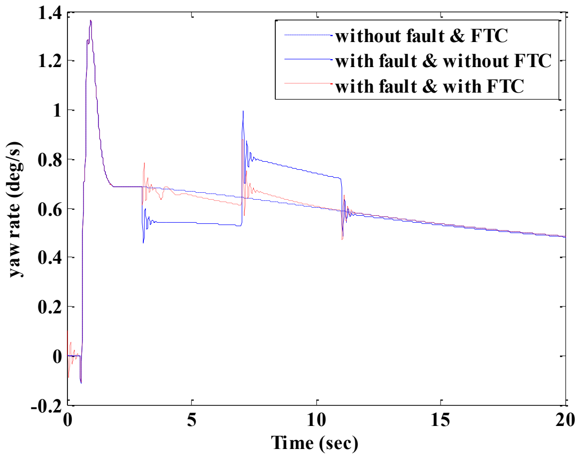

Fig. 3. Time history of yaw rate

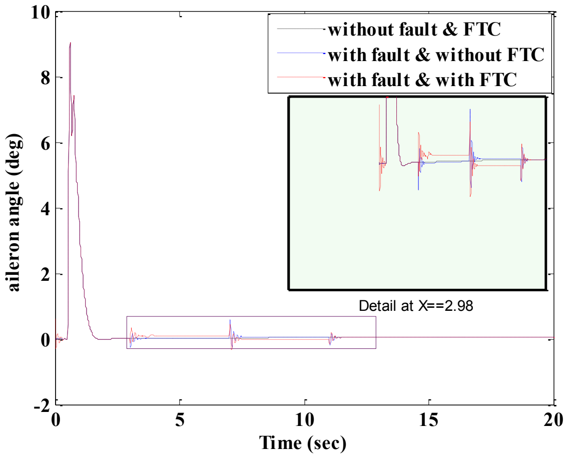

Fig. 4. Time history of aileron deflections

on a back-stepping approach.

Nonlinear six-degree of freedom dynamic equations of aircraft in body airframe, assuming a flat earth model are used as plant model.

3- Results and Discussion

In this section, the designed control system's effectiveness in compensating errors arising from the yaw rate sensor is evaluated, in the first simulation. In order to validate the proposed algorithm, three types of smooth, sudden, and temporary errors are simulated. In the error identification and separation part, the designed adaptive neural observer is used. Time variations of yaw rate are shown in Fig. 3 for without fault & with Fault Tolerant Control (FTC), with fault & without FTC, and with fault & with FTC conditions. The aileron deflection variations are also drawn in Fig. 4.

In another simulation, utilizing a predefined time history for the angle of attack, roll angle, and side slip angle, as the

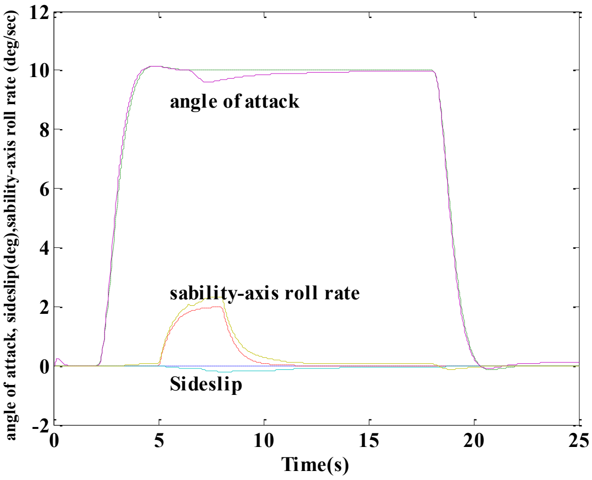

Fig. 5. Time history of the angle of attack, roll angle, and side slip angle in presence of a fault in comparison with commanded signals.

control system desired input, a maneuver is designed for the airplane. In this simulation, all three angular rate sensors are assumed to have faults from 3rd second of flight. Fig. 5 shows the predefined control system commands and the track ones in presence of a fault in angular rate sensors. Here, the sudden fault is added to the system. Simulations revealed that the designed control system can effectively compensate for the sudden fault effects in flight.

4- Conclusions

Current research introduces a novel approach to fault detection. In this approach, an adaptive neural network is designed and neural network weighting parameters are tuned by the Extended Kalman filter. The proposed approach is implemented on an F-18 airplane during a maneuvering flight. The simulation results indicate that the proposed approach is effectively capable to identify and detect different types of errors. The designed fault tolerant controller compensates for the undesirable effects of sensor defects. Comparing the current approach with those of state of art ones shows that it has a superior performance in fault detection as well as in fault compensation by the designed control system.

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