Application of Model Reference Adaptive Control to General Aviation

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Abstract. In an effort to increase general aviation safety, model reference adaptive control (MRAC) is applied to a dynamic simulation of the Hawker Beechcraft CJ-144 fly-by-wire aircraft. MRAC controls the aircraft in the nominal case and adapts to maintain control during unexpected failures. An artificial neural network is trained online to correct for uncertainty and to adapt to changes or failures in the aircraft. The aircraft response is shaped by a model following linear controller. A time delay metric is used to tune the controller gains. Time response results are presented. This controller is designed to be flight tested on the CJ-144 aircraft.

1. Introduction

Safety will always be a paramount concern in aviation. Ongoing research efforts at NASA and the DOD investigate the use of model reference adaptive control (MRAC) to increase aviation safety, in the event of a failure. MRAC was initially applied in aviation through the work of Kim and Calise [1], with promising results. Since that time NASA has successfully flight tested Calise's algorithms on an F-15 demonstrator [2]. Previous work at Wichita State has investigated the application of MRAC to general aviation for the longitudinal axis [3], [4]. The new work here extends that effort to six degrees of freedom. With Hawker Beechcraft Corporation, Wichita State has the opportunity to flight test algorithms in order to validate these methods. The development and simulated performance of the six degrees of freedom controller are presented in this paper.

2. Experiment, Results, Discussion, and Significance

The controller consists of three main elements, the inverse controller, the artificial neural network, and the model following linear controller and four output feedback loops, one each for airspeed, flight path angle, bank angle, and side force. The inverse controller calculates the necessary aircraft control actuations from the commanded accelerations and the adaptation signal. The inverse controller is derived as the inverse of the nonlinear aircraft at the nominal flight condition. Therefore when the nominal flight condition is deviated from, due to change in flight condition or damage to the aircraft, the inverse becomes less precise. The role of the neural network is to reduce any modeling error or uncertainty in the inverse. This is especially important during emergency situations where damage has changed the dynamics of the aircraft. Each of the four control loops has a single bias neuron, which learns online to reduce the error between the desired and actual value of its respective parameter. The parameters of the model following controller and the proportional-derivative controller are chosen to produce the desired system response characteristics (i.e. rise time, overshoot, damping ratio, etc.). The model follower and linear controller gains were selected so that the aircraft achieves the desired time response. A time delay metric for adaptive controllers, was developed by NASA [5] and is used in this research to aid the gain selection process. A delay is inserted in the signal from the inverse controller to the aircraft and the effect of this delay is observed during a maneuver in that axis. The delay is subsequently increased until the error becomes large. The time delay metric gives two key parameters. The first parameter is the Time Delay Margin which is the length of delay that can be inserted into the control signal before the aircraft becomes unstable. This is a measure of system robustness. The second parameter is the Zero Delay Error which is the value of the 2-norm of the tracking error with no delay in the system. This is a measure of tracking precision. Therefore the best controller gains would achieve the desired time response while maximizing the Time Delay margin and minimizing the Zero Delay Error.

Fig. 1 shows the aircraft flight path angle response, the elevator response, and the pitch adaptation signal, to an unexpected failure. In this scenario there is a 50% loss of elevator effectiveness at 10 seconds, followed by a negative 3 degree flight path angle command at 50 seconds. The six degrees of freedom adaptive controller is able to adapt after the failure to maintain stability and conduct the desired maneuvers.

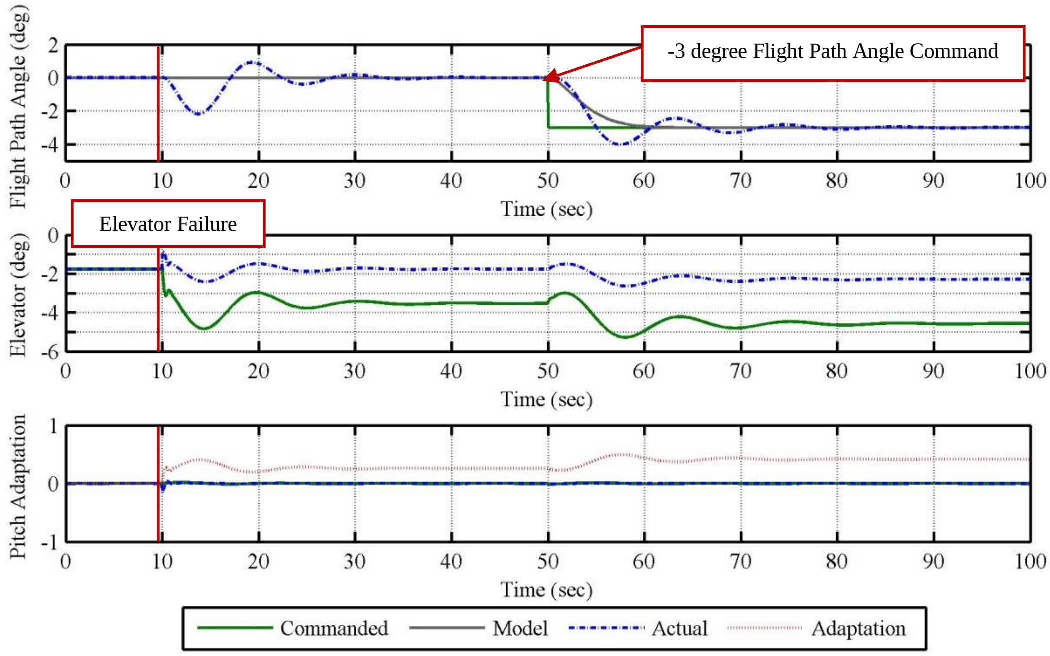

Fig. 1. Flight path angle and pitch neural network response to simulated 50% reduction in elevator effectiveness (10s), negative 3 degree flight path angle command (20 s), 50% reduction in thrust (90s) and 10 ft/sec increase in airspeed (100s)

3. Conclusions

MRAC has been adapted in simulation to the Hawker Beechcraft CJ-144 aircraft. The inverse controller was derived in six degrees of freedom, a single bias neuron is used as the artificial neural network, and the model following linear controller is used to shape the response. A gain selection study using an artificial time delay is used to select the controller gains. The controller is shown to perform well in the nominal case. Additionally the controller is able to maintain stability and execute maneuvers in emergency situations. The objective of this research is to increase general aviation safety through the acceptance of this technology

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