Aerodynamic Parameter Estimation for Adaptive Flight Control System

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1. Introduction

The research is part of an FAA-Raytheon Aircraft sponsored project for the development of a Neural based Adaptive Flight Control System. The Adaptive Control System uses Neural Networks for an immediate adaptation to modeling errors or failures. This results in the controller using parameters that no longer model the actual aircraft. Online Parameter Identification improves adaptation as the modeling error is reduced. It also provides a long-term secondary tool for adaptation, apart from neural networks that provide primary immediate adaptation. Unlike other Statistical Parameter Estimation techniques, this technique uses simple equations to update the parameters, which then are used in the controller.

2. Description of Parameter Estimation Technique.

2.1) Neural Based Adaptive Flight Control System.

Unlike most of the modern control systems, an Inverse Controller is used to calculate elevator and throttle (for longitudinal control) from given Linear and Angular accelerations required to maintain commanded Airspeed and Flight Path Angle. As shown in the figure-1, a simple feedback PID controller is used to track the command Airspeed and Flight Path Angle. Another feedback loop through an Artificial Neural Network is added, which provides adaptation to modeling errors by increasing or decreasing the inputs to the Inverse Controller, when required. [1]

The Neural Network looks at the error between the commanded input and the actual response of the Aircraft, and outputs an error compensation signal which is added in the respective input to the Inverse Controller. The Neural Network is capable of adapting to the dynamics of the Aircraft and adding an immediate adaptation to correct for modeling error, which can be caused due to change in center of gravity, change in weight, change in elevator response etc.

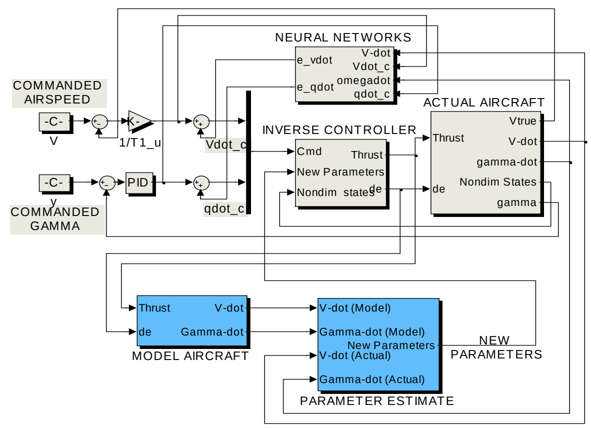


Figure 1. Modified Neural Based Adaptive Flight Controller

Figure 1 shows the simulation setup for the system. Lighter blocks represent the standard Neural based Adaptive flight controller, and the darker blocks shows the addition of the Parameter Estimation technique.

2.2) Description of parameter estimation technique:

A Linear Aircraft Model is added. It uses an inverse of the equations used in inverse controller [1], and the same parameters as used in the inverse controller. The outputs of this block are the linear and angular accelerations, given by the equations below.

$$\dot{V} = \left(T.\cos(\alpha + \phi_T) - \bar{q}.S.(C_D)_{\delta_e=0} - m.g.\sin(\gamma)\right)/m$$

where $(C_D)_{\delta_e=0} = C_{D0} + C_{DK}.(C_{L0} + \alpha.C_{L\alpha})^2$

$$\ddot{\gamma} = \left(\delta_e.C_{M\gamma_e} + (C_M)_{\gamma_e=0} - \left(T.d_T/(\bar{q}.S.\bar{c})\right)\right).(\bar{q}.S.\bar{c})/I_{yy} - \ddot{\alpha}$$

where $(C_M)_{\delta_e=0} = C_{M0} + \alpha.C_{M\alpha} + \hat{\dot{\alpha}}.C_{M\dot{\alpha}} + \hat{q}.C_{Mq}$

In the estimator block, calculated $\dot{V}_{Model}$ and $\ddot{\gamma}_{Model}$ values are compared with $\dot{V}_{Actual}$ and $\ddot{\gamma}_{Actual}$ that we get from actual aircraft. So the errors are defined as:

$$\dot{V}_{error} = \tfrac{1}{2}\left(\dot{V}_{Actual} - \dot{V}_{Model}\right)^2.sign\left(\dot{V}_{Actual} - \dot{V}_{Model}\right)$$

$$\ddot{\gamma}_{error} = \tfrac{1}{2}\left(\ddot{\gamma}_{Actual} - \ddot{\gamma}_{Model}\right)^2.sign\left(\ddot{\gamma}_{Actual} - \ddot{\gamma}_{Model}\right)$$

At a given flight condition, if the parameters used in the Inverse Controller and Aircraft Model are the same as that of the Actual Aircraft, the values of $\dot{V}_{error}$ and $\ddot{\gamma}_{error}$ will be zero. But the presence of nonzero error indicates incorrect parameters in the Aircraft Model and the magnitude is directly proportional to the error in the aerodynamic parameters.

The Parameter estimation block uses gradient descent to update the parameters as follows. The linear Aircraft equations (for $\dot{V}$ and $\ddot{\gamma}$) are differentiated w.r.t. each parameter, multiplied by the respective errors and added to the parameter value at previous time step.

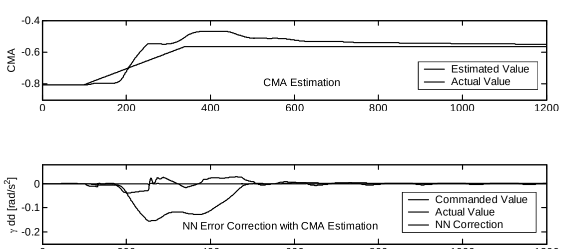
The equation to update $C_{M\alpha}$ is:

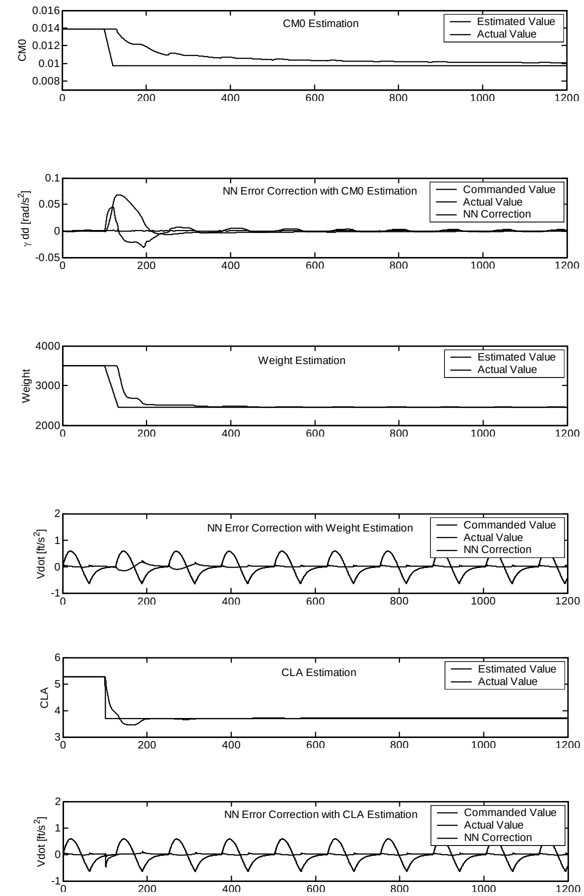
$$C_{M\alpha}(t) = C_{M\alpha}(t-1) + K.\left(\partial\ddot{\gamma}/\partial C_{M\alpha}\right)\ddot{\gamma}_{error}$$

where K is a learning rate. Similar update equations are defined for each parameter. Notice there are only two equations (for $\dot{V}$ and $\ddot{\gamma}$), which we use to update the parameters. But the number of parameters to be updated is certainly more than two, this leads to a problem of more unknowns than equation to solve. Changing the flight condition can generate additional equations. A certain flight maneuver is repeated periodically and each parameter is updated at a specific part of the maneuver. The maneuver used is a half sinusoidal variation in the commanded airspeed varying from 130 to 142 knots.

2.3) Results:

As the estimated parameters are updated in the inverse controller the neural network correction by definition goes to zero. This shows that the new parameters are certainly a close match of those in the actual aircraft. To test the algorithm, in each case one parameter was deliberately changed in the actual aircraft after 100 sec, and at the same time all the parameters in the controller were allowed to adjust. Four sets of plots were generated for four parameters; the first plot shows the adaptation of $C_{M\alpha}$ w.r.t. time followed by the plot of Neural Network error change due to $C_{M\alpha}$ adaptation. The other six plots show adaptation of C_{M0}, Weight, $C_{L\alpha}$ and their corresponding Neural Network errors.





3. Conclusion

The Results demonstrate the ability of the parameter estimation technique to improve overall adaptation of the control system. Though the technique is slow as compared to most of the other online parameter estimation techniques but it is desired as the Neural Network does fast adaptation followed by slow long-term adaptation by this method. Certainly the technique is computationally very simple and needs less processing power than other techniques. More work is desired to improve the convergence speed of parameters and increase the number of parameters estimated at same time.

4. References

[1] Pesonen, U.J., Steck, J.E. and Rokhsaz, K. (2004) "Adaptive neural network inverse controller for general aviation safety", in *AIAA Journal of Guidance, Control and Dynamics Vol 27*.

[2] G Campa, M Napolitano, B Seanor, MG Perhinschi "Online Parameter Estimation Techniques Comparison Within a Fault Tolerant Flight Control System" in *AIAA Journal of Guidance, Control and Dynamics Vol. 25.*