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Online Identification for Aerodynamic Parameters of the Damaged Aircraft

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Abstract. Based on the wing damaged aircraft for background, the online identification method of mutational parameters was studied. After structure damaged, the symmetry of the aircraft was broken, causing the pneumatic structure of the vertical and horizontal highly coupled. To identify the aerodynamic parameters, firstly aerodynamic forces and moments were estimated as the output data of identification. Then the model of identification was selected according to the coupled pneumatic structure. Finally an identification method called Limited Recursive Least Squares (LRLS) was introduced, in which forgetting factor, weight matrix and limit item were used. The simulation results show that this method is capable to resolve the problem of strong coupling and sudden changing, while meeting the real time and accuracy requirement of online identification.

Introduction

The structure damage of aircraft can reduce the flying qualities, and even undermine the stability of the flight control system which could cause a crash. Therefore, aerodynamic parameter identification has become a major issue to improve the flight safety.

In the 1990s, NASA conducted a research on IFCS project. And in 2003, they provided the control system aerodynamic parameters identified by neural network offline[1]. In 2004, GARTEUR established a dedicated team called FM-AG 16 to make a study on fault-tolerant flight control. The aerodynamic parameters are identified online to adjust dynamic inverse control law[2].

However the online identification of structure damaged aircraft has the following difficulties:(1)It is preferred to choose a smaller time window to trace the time-varying parameters while flying. As a result the identification error become bigger.(2)The input signal is determined by the control law instead of being choosing freely. The identification may become divergent when input signal is weak.

In order to overcome these difficulties, this paper studies on Limited Recursive Least Squares (LRLS) using forgetting factor, weight matrix and limit item.

Architecture

Figure 1 shows adaptive dynamic inverse reconfiguring flight control scheme[1,2,3]. In the Online Identification module, input are rudder bias, aircraft states, aerodynamic forces and moments provided by the Aerodynamic Force and Moment Estimate module. Output is identification results of aerodynamic parameters. It is used to update the dynamic inverse controller and act on the attitude control of the aircraft.

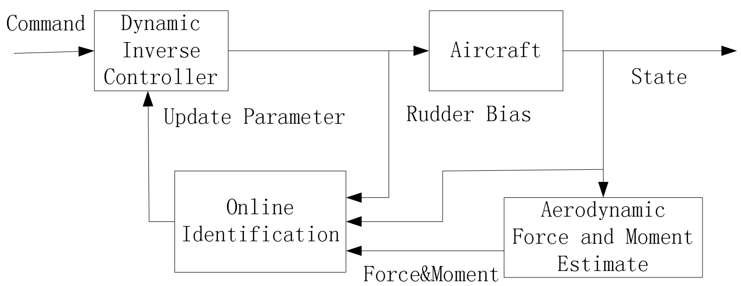

Fig 1 Dynamic inverse control system based on the identification of aerodynamic parameters

Estimates of aerodynamic forces and moments

A key question of the identification is the determination of the forces and moments acting on the aircraft. As they can't be measured directly, we can calculate them by using linear velocity, linear acceleration, angular velocity and angular acceleration.The calculation of the dimensionless force and moment is as follows:

$$C_X = \frac{X}{1/2\rho V^2 S} = \frac{mA_x - T_x - G_x}{1/2\rho V^2 S} \tag{1}$$

$$C_Y = \frac{Y}{1/2\rho V^2 S} = \frac{mA_y - T_y - G_y}{1/2\rho V^2 S} \tag{2}$$

$$C_Z = \frac{Z}{1/2\rho V^2 S} = \frac{mA_z - T_z - G_z}{1/2\rho V^2 S} \tag{3}$$

$$C_l = \frac{L}{1/2\rho V^2 Sb} = \frac{\dot{p}I_{xx} + qr(I_{zz} - I_{yy}) - (pq + \dot{r})I_{xz}}{1/2\rho V^2 Sb} \tag{4}$$

$$C_m = \frac{M}{1/2\rho V^2 S\bar{c}} = \frac{\dot{q}I_{yy} + rp(I_{xx} - I_{zz}) - (p^2 - r^2)I_{xz}}{1/2\rho V^2 S\bar{c}} \tag{5}$$

$$C_n = \frac{N}{1/2\rho V^2 Sb} = \frac{\dot{r}I_{zz} + pq(I_{yy} - I_{xx}) - (qr - \dot{p})I_{xz}}{1/2\rho V^2 Sb} \tag{6}$$

Model selection for identification

The symmetry of the aircraft is broken after it is damaged and causing that the lateral and longitudinal of the aircraft model are highly coupled. The following formulas contain the parameters of the aerodynamic model to be identified. The items in the box are added due to the coupling of the damaged aircraft and they represent the contribution from the longitudinal state to the lateral forces and moments and from the lateral state to the longitudinal forces and moments. These items can only appear in the asymmetric damaged aircraft and they will be zero in the traditional symmetric aircraft.

$$C_X = C_{X0} + C_{X\alpha}\alpha + C_{X\alpha^2}\alpha^2 + C_{Xq}\frac{q\bar{c}}{V} + C_{X\delta e}\delta e + \boxed{C_{Xp}\frac{pb}{2V} + C_{Xr}\frac{rb}{2V}} \tag{7}$$

$$C_Z = C_{Z0} + C_{Z\alpha}\alpha + C_{Zq}\frac{q\bar{c}}{V} + C_{Z\delta e}\delta e + \boxed{C_{Z\delta a}\delta a + C_{Z\beta}\beta + C_{Zp}\frac{pb}{2V} + C_{Zr}\frac{rb}{2V}} \tag{8}$$

$$C_m = C_{m0} + C_{m\alpha}\alpha + C_{mq}\frac{q\bar{c}}{V} + C_{m\delta e}\delta e + \boxed{C_{m\delta a}\delta a + C_{m\delta r}\delta r + C_{m\beta}\beta + C_{mp}\frac{pb}{2V} + C_{mr}\frac{rb}{2V}} \tag{9}$$

$$C_Y = C_{Y0} + C_{Y\beta}\beta + C_{Yp}\frac{pb}{2V} + C_{Yr}\frac{rb}{2V} + C_{Y\delta a}\delta a + C_{Y\delta r}\delta r + \boxed{C_{Y\alpha}\alpha + C_{Yq}\frac{q\bar{c}}{V}} \tag{10}$$

$$C_l = C_{l0} + C_{l\beta}\beta + C_{lp}\frac{pb}{2V} + C_{lr}\frac{rb}{2V} + C_{l\delta a}\delta a + C_{l\delta r}\delta r + \boxed{C_{l\alpha}\alpha + C_{lq}\frac{q\bar{c}}{V}} \tag{11}$$

$$C_n = C_{n0} + C_{n\beta}\beta + C_{np}\frac{pb}{2V} + C_{nr}\frac{rb}{2V} + C_{n\delta r}\delta r + \boxed{C_{n\alpha}\alpha + C_{nq}\frac{q\bar{c}}{V}} \tag{12}$$

Limited Recursive Least Squares (LRLS)

(1) forgetting factor

The aerodynamic parameters of aircraft change with flight state. The present sampling data reflects the dynamic characteristics of the suspicious object best, while old sampling data may lead the identification results far away from the dynamic characteristics of the suspicious object. To trace the changes of parameters, forgetting factor is used to deal with the sampling data. Index function is as follows:

$$J = \left(Y(N) - \Psi(N)\hat{\Theta}(N)\right)^T W(N)\left(Y(N) - \Psi(N)\hat{\Theta}(N)\right) \tag{13}$$

Where $W(N) = diag[\lambda^{N-1}, \cdots \lambda, 1]$, λ represents forgetting factor.

(2) limit item

The identification of damaged aircraft parameters faces a problem of larger estimate errors caused by morbid regression matrix. It is useful to take advantage of transcendental experience. The literature [4,5]used Limited Recursive Least Squares with transcendental experience which is stored offline. Index function is as follows:

$$J=\left(Y(N)-\Psi(N)\hat{\Theta}(N)\right)^T W(N)\left(Y(N)-\Psi(N)\hat{\Theta}(N)\right)+\left[\left(\hat{\Theta}_N-\Theta_{No}\right)^T G_N{}^T G_N\left(\hat{\Theta}_N-\Theta_{No}\right)-1\right] \quad (14)$$

Where Θ_{No} and G_N are prior experience used by the N times identification.

(3) weight matrix

In the algorithm of LRLS, the selected limit items have a great influence on the identification result. Different limit parameter has different effects on the index function. The parameter which has small magnitude may lead to bigger errors than the one which has large magnitude. So we need to introduce a weight matrix to make sure all limit parameters are on the same order of magnitude. Rewrite the index function as follows:

$$J=\left(Z(N)-\Psi(N)\hat{\Theta}(N)\right)^T W(N)\left(Z(N)-\Psi(N)\hat{\Theta}(N)\right)+U\left[\left(\hat{\Theta}_N-\Theta_{No}\right)^T G_N{}^T G_N\left(\hat{\Theta}_N-\Theta_{No}\right)-1\right] \quad (15)$$

Where $U = diag(u_1, u_2, \ldots, u_m)$ represents the limit parameter weights matrix, and m represents the number of identification parameters. The recursive formula is as follows:

$$P_{N+1} = \lambda P_N - \lambda G_N^T U G_N + \psi_{N+1}\psi_{N+1}^T + G_{N+1}^T U G_{N+1} \quad (16)$$

$$\hat{\theta}_{N+1} = \hat{\theta}_N + P_{N+1}^{-1}\psi_{N+1}(Y_{N+1} - \psi_{N+1}^T\hat{\theta}_N) + P_{N+1}^{-1}[(\lambda G_N^T U G_N - G_N^T U G_N)\hat{\theta}_N - \lambda G_N^T U G_N \theta_{N0} + G_{N+1}^T U G_{N+1}\theta_{N+1,0}] \quad (17)$$

Validation on estimate of the aerodynamic forces and moments

To verify the accuracy of the aerodynamic forces and moments, we simulate the situation of that aircraft is damaged with 20% at time T=3 second. As can be seen from figure 2, before aircraft is damaged, the estimation error is small. However, the error increases when aircraft is damaged. The internal reasons are the changes in mass, inertia, wing area.

However, we ignore the above changes in this paper. The reason is that the damage to the aircraft is unknown. And in real flight, we cannot know the changes of mass, inertia, and wing area accurately.

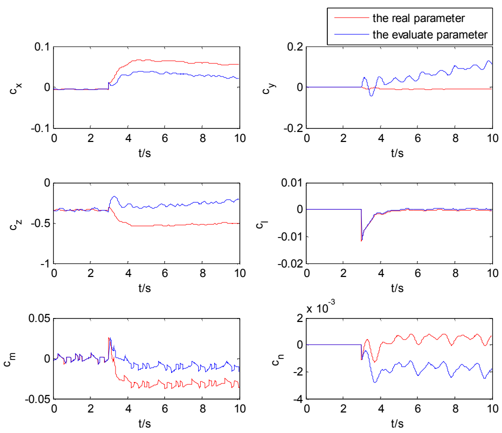

Fig.2.The results of estimating aerodynamic force and moment

Validation on identification of the aerodynamic parameters

To verify LRLS to slow changing parameters, undamaged aircraft is simulated. The rudder bias is trim value at initial time and 10% inverse M sequences of disturbances are added. As shown in figure 3, the identification parameters can reflect the changes of derivative of various forces and moments.

To verify LRLS to mutational parameters, we simulate the situation of that aircraft is damaged 20% at time T=3 second. As we can see from figure 4, aerodynamic parameters change abruptly when the aircraft become damaged. And the identification of parameters can trace this variation quickly .

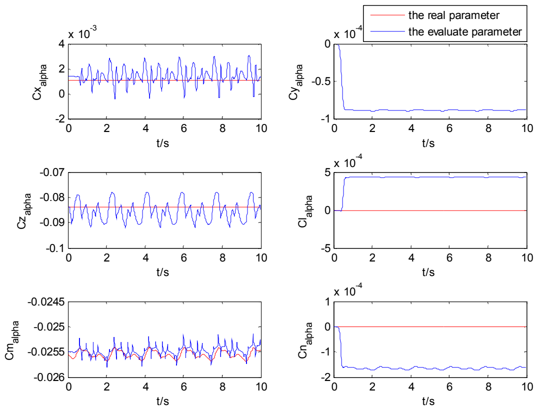

Fig. 3. Online identification while undamaged

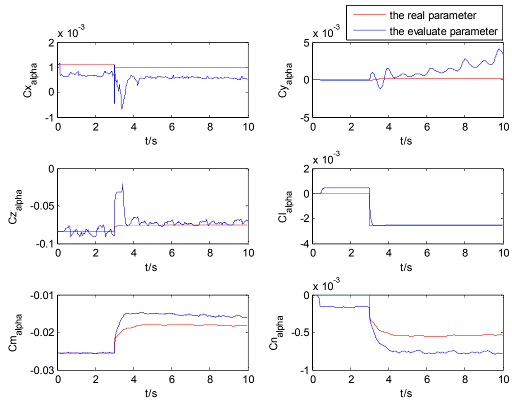

Fig. 4. Online identification while damaged 20%

Conclusions

In this paper, Limited Recursive Least Squares method is used to identify the aerodynamic parameters of aircraft. (1)Forgetting factor is introduced to trace the aerodynamic parameters of the time-varying characteristics; (2)The limit item use transcendental experience to improve the morbid information matrix, and ensure the precision of the estimates parameters while there is not enough inspire; (3)The weight matrix can regulate the effect of limit parameters with different magnitude on the index function. Cruise flight and damaged flight status simulations shows that this method can solve the online identification problems in strong couple and sudden change situation. However, the disadvantage of this identification method is that the error is larger after the aircraft is damaged. So the future work is to add some appropriate compensation.

Acknowledgements

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