

A Predictive Control Methodology for Pitch Pointing and Altitude Rate Modes

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Abstract

A predictive control methodology is applied for designing pitch pointing and vertical translation flight control laws as an alternative to the eigenstructure assignment methodology developed by Sobel and Shapiro (Sobel and Shapiro, 1983). This methodology discards the eigenstructure assignment design to decouple the pitch attitude and flight path angle. Feedback gains are computed using a trivial place pole tool without eigenvector assignment. The design methodology is illustrated by applications to F-16 aircraft longitudinal reduced linear model.

Keywords: predictive control, aircraft control, pitch-pointing, neural networks

Introduction

This paper explores an alternative approach to the Andry, Sobel, Shapiro and Chung papers (Andry et al 1983, Sobel and Shapiro 1985, Sobel et al 1994) about CCV (control configured vehicles) for augmenting the weapon aiming envelopes providing non-typical maneuvers by alternative control laws. The Srinathkumar (Srinathkumar, 1978) theorem gives the basis for controlling decoupled modes in linear systems.

The predictive control methodology allows to constraint the the degrees of freedom in the design phase. A quadratic performance index taking into account the outputs errors and control smoothness, as well as the outputs weighting to be selected for controlling is to be minimized by any optimization method. The constrained outputs can be implemented meeting the control surface deflection saturation limits.

Herein the illustration is based in a linear model and it has the objective of comparing approaches only. The nonlinear plant models as well as identification models based on Artificial Neural Networks are also being analyzed for getting more realistic solutions.

Predictive Control Methodology

Consider a dynamic system described by the Space State form:

$$\begin{aligned}\dot{x} &= f(x, u) \\ y &= h(x, u)\end{aligned}\tag{Eqs.1}$$

where $x \in R^n$, $u \in R^m$, $y \in R^r$

The method consists minimize the permormance index as following;

$$J = \sum_{j=1}^n [y(t_j) - \hat{y}(t_j)]^T R_y^{-1}(t_j) [y(t_j) - \hat{y}(t_j)] + \frac{1}{2} \sum_{j=0}^{n-1} [u(t_j) - u(t_{j-1})]^T R_u^{-1}(t_j) [u(t_j) - u(t_{j-1})]\tag{Eq. 2}$$

where the output error and control smoothing are weighted in the quadratic form and, under the constraints:

$$\min y \leq (y(t_j)) \leq \max y, \quad \min u \leq (u(t_j)) \leq \max u, \quad (u(t_j) - u(t_{j-1})) \leq \max \Delta u\tag{Eqs. 3}$$

The optimization method to carry out the performance index and constraints, subject to the system dynamic (Eqs.1), shall be a local minimization because the output and control constraints shall be evaluated a each sample time. The MPC Matlab toolbox was used for simulating it.

Example

This example is based on the F-16 longitudinal mode used on previously mentioned paragraphs. The longitudinal mode is shown in the Eqs. 4.

$$\dot{x} = Ax + Bu$$

$$y = Cx$$

where,

$$x = \begin{bmatrix} \theta \\ q \\ \alpha \\ \delta_e \\ \delta_f \end{bmatrix} \quad \begin{array}{l} \theta - \text{pitch attitude} \\ q - \text{pitch rate} \\ \alpha - \text{angle of attack} \\ \delta_e - \text{elevator deflection} \\ \delta_f - \text{flaperon deflection} \end{array} \quad u = \begin{bmatrix} \delta_{ec} \\ \delta_{fc} \end{bmatrix} \quad \begin{array}{l} \delta_{ec} - \text{elevator deflection command} \\ \delta_{fc} - \text{flaperon deflection command} \end{array}$$

$$A = \begin{bmatrix} 0 & 1 & 0 & 0 & 0 \\ 0 & -0.87 & 43.22 & -17.25 & -1.58 \\ 0 & 0.99 & -1.34 & -0.17 & -0.25 \\ 0 & 0 & 0 & -20 & 0 \\ 0 & 0 & 0 & 0 & -20 \end{bmatrix} \quad B = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 20 & 0 \\ 0 & 20 \end{bmatrix} \quad C = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (\text{Eqs.4})$$

The system open loop eigenvalues are:

$$\begin{array}{ll} \lambda_1 = -7.66 & \text{unstable short period mode} \\ \lambda_2 = 5.45 & \\ \lambda_3 = 0.0 & \text{pitch attitude mode} \\ \lambda_4 = -20 & \text{elevator actuator mode} \\ \lambda_5 = -20 & \text{flaperon actuator mode} \end{array} \quad (\text{Eqs.5})$$

The closed loop eigenvalues are obtained using Matlab place function.

$$\Lambda = [-5.6 + 4.2j, -5.6 - 4.2j, -1, -19, -19.5]$$

The maximum control surface deflection and deflection rates are:

$$\begin{array}{ll} \delta_e \text{ max} = \pm 25 \text{ deg} & \dot{\delta}_e \text{ max} = 42 \text{ deg/s} \\ \delta_f \text{ max} = \pm 20 \text{ deg} & \dot{\delta}_f \text{ max} = 56 \text{ deg/s} \end{array} \quad (\text{Eqs.6})$$

The objective in pitch pointing control is to command the pitch attitude θ while maintaining flight path angle γ null. The flight path angle is directly associated to the altitude rate in the form:

$$\gamma = \dot{h} / TAS \quad (\text{Eq.7})$$

where TAS is the True Airspeed

The path angle γ is related with attack angle α as:

$$\theta = \gamma + \alpha \quad (\text{Eq.8})$$

The problem is well posed for using a predictive control method because the outputs horizon (pitch angle and altitude rate) are constant.

It is shown in the Fig.1 the target outputs for 5° path angle demand and 0° pitch angle demand. It is observed that there is a saturation in the path angle due to the limits imposed on the command surfaces (Eqs. 6).

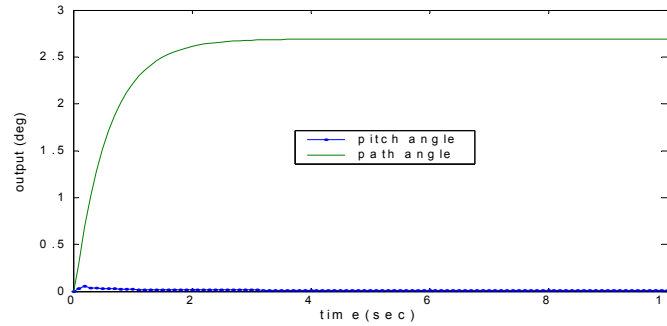


Figure 1 – Outputs θ (pitch) e γ (path angle) (deg)

The command surfaces are subject at the constraints (Eqs.6). The Fig. 2 shows these outputs and the flaperon constraint is evident.

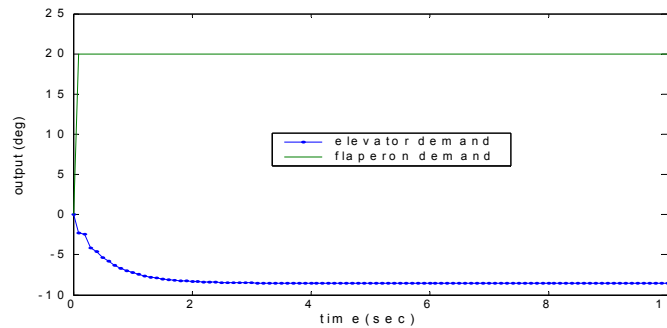


Figure 2 – Elevator δ_e and flaperon δ_f demands (deg)

The pitch pointing mode was also simulated and its performance was satisfactory.

Conclusion

The results show the possibility of using the predictive control approach for modes decoupling in the CCV aircraft control. The poles allocation was implicitly performed without eigenvector consideration. Several possibilities can still be explored, as for example the use of neural networks for plant identification, allowing the application to non-linear systems.

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