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Self Adjusting Digital Controller for Aircraft Systems.

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SELF ADJUSTING DIGITAL CONTROLLER FOR AIRCRAFT SYSTEMS

تحكم الطائرة الرقمى ذاتى الضبط

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يقدم البحث طريقه لتصميم المحكمات الرقميه ذاتية الضبط التى تستخدم فى التحكم فى الطائرات لكى تتناسب مع تغير معاملات الطائرة التى تنشأ من تغير حالات الطيران • يتم التحكم بالقياس المستمر لمعاملات الطائرة التى تعتمد على حالة الطيران ومقارنة هذه المعاملات المقاسه بحيز نطاقى يخلق حول معاملات حالة طيران محددة • أى انحراف لهذه المعاملات المقاسه عن الحيز النطاقى يحدث اضطراب فى دليل محكم الطائرة للحصول على دوال حساسية تستخدم هذه الدوال فى ضبط معاملات التغذيه الرجعيه للمحكم والنظام المقترح مناسب للتطبيق على المحكمات الحقيقيه وتصميم هذا المحكم يمثل امتداد للتصور المعطى فى (١) •

ABSTRACT

The paper describes an algorithm for designing self adjusting optimal controller for digital aircraft control systems to cope with the variation of the aircraft parameters under different flight conditions. The aircraft parameters which depend on the flight condition are continuously measured. A deadband zone around each of the parameters of a presetting flight condition is initiated. Any deviation from these bands will individually perturb the controller reference for obtaining sensitivity functions. These sensitivity functions will be used to adjust the feedback parameters of the aircraft control system.The propoeed technique is suitable for implementation on real world control systems. The design of the proposed control represents an extension for that concepts included in [1].

INTRODUCTION

Aircraft control laws have been designed with modern linear quadratic technique [2,3] appropriately tempered with established classical design requirements. In this type of design, the quadratic optimization problem was formulated and solved at selected flight conditions under assumptions of noiseless, full state and continuoues time feedback. The resulting control gains and dynamics were then simplified and approximated as functions of measurable nominal flight condition parameters to produce standard gain control laws. However, such a controller may fail to cope with every flight condition, because of the variation of the aircraft parameters .

Different techniques for designing robust aircraft controller complying with prescriptive range of flight condition are also proposed [4,5,6] . However, these techniques does not guarantee the stability of the closed-loop system when subjected to perturbations in flight conditions.

This paper introduces a technique using the parameter sensitivity functions , resulted from variation in flight conditions, for adjusting the parameters of control systems. The proposed technique does not require any system identification except for the controller. The method offers the possibility of adjusting the parameters of optimal or suboptimal control schemes which have been installed on real systems.

AIRCRAFT SELF ADJUSTING DIGITAL CONTROLLER

The longitudinal linearized dynamic equations of an aircraft for deriving self adjusting controller, may be written as:

$$\dot{y} = A\,y + B\,v \qquad y(0) = 0 \tag{1}$$

$$v = v_r - K\,y \tag{2}$$

Where :

A , B and y are defined [7] as:

$$A = \begin{vmatrix} z_1 & 1.0 & z_3 \\ M_1 & M_2 & M_3 \\ 0 & 0 & -a_3 \end{vmatrix}$$

$B = [\ 0 \quad 0 \quad a_3\ ]$,

$y = [\ y_1 \quad y_2 \quad y_3\ ]$,

y_1 the angle of attack ;
y_2 the rate of pitch angle ;
y_3 the incremental elevator angle ;
v the control input to the elevator;
v_r the step disturbance of magnitude k_r
K the feedback matrix.

The approximate functional descriptions for the coefficients of the matrix A ($z_1, M_1, M_2, M_3, z_3, a_3$) vary from a flight condition to another but all coefficients have the form [6] :

$$P_i = g\ (\ q_0,\ Mach_0,\ C\ )$$

Where : q_0 is the dynamic pressure ,
C is a small perturbation parameter $0.13 < C < 2.0$
M_1 , M_2 , M_3 , Z_1 dynamic coefficient (function of C)
$Mach_0$ is the mach coefficient
a_3 function of C and q_0

Implementation of the proposed method is based upon:

(1) Initiate presetting flight conditions q_0' and $mach_0$.
(2) Define deadband zones around these conditions.

upperband
$q_0 + \Delta q$
$Mach_0 + \Delta\ Mach$
lower band
$q_0 - \Delta\ q$
$Mach_0 - \Delta\ mach$

where, $\Delta\ q$, and Δ Mach are permissible changes that retain system stability when occured .

(3) If the flight condition exceed the permiseible changes , a step disturbance of variable size individualy perturb the

controller reference of the system for obtaining sensitivity functions.

(4) Using these functions the controller parameters are adjusted .

The value of the variable size input k_r is defined as [1].

$$k_r = 1 + K\, y_r \tag{3}$$

$$y_r = -(A - B\,K)^{-1}\, B\, k_r \tag{4}$$

This value keeps the final values of system independent of the feedback parameters K ,

Equations (1) and (2) when restated in phase variable form become:

$$y_i\,(s) = W_i\,(s)\,.\,v(s) \quad \text{for } 1 < i < n \tag{5}$$

$$v(s) = k_r(s) - \sum_{j=1}^{n} K_j\,.\,y_j\,(s) \tag{6}$$

Substituting equation (6) into equation (5) gives:

$$y_i(s) = x_i(s)\;.k_r(s) \quad \text{for } 1 < i < n \tag{7}$$

where

$$x_i(s) = \frac{W_i\,(s)}{1 + \sum_{j=1}^{n} K_j\,.\,W_j\,(s)} \tag{8}$$

The sensitivity of variable y_i with respect to parameter K_j is then :

$$S_{K_j}^{y_i} = \frac{\partial\, y_i}{\partial\, K_j} = \frac{\partial\, x_i(s)}{\partial\, K_j}\;.\;k_r + x_i\,(s)\;.\frac{\partial\, k_r}{\partial\, K_j} \tag{9}$$

When this equation is expanded and restated in sampled form it becomes :

$$S_{k_j}^{y_i}(\alpha . \Delta t) = \frac{1}{k_r} [\sum_{\beta=1}^{\alpha} - \frac{y_i(\alpha . \Delta t) - y_i((\beta - 1) . \Delta t)}{\Delta t}$$

$$y_i(\alpha . \Delta t - \beta . \Delta t)] + \frac{1}{k_r} . y_{rj} . y_i (\alpha . \Delta t) \quad \text{for} \quad 1<\alpha<n_s \qquad (10)$$

where : n_s = number of samples
Δt = sampling interval
$y_i(0) = 0$ for $1 < i < n$

The last equation can then be used in calculating the changes of the feedback parameters necessary to cope with the changes in flight conditions.

The time response of variable i after change ΔK in the parameter matrix K, $y_i(t,K+\Delta K)$ is related to the time response before the changes, $y_i(t,K)$ by the equation:

$$y_i(t,K+\Delta K) = y_i(t,K) + \frac{\partial y_i}{\partial K} \Delta K + \frac{\partial^2 y_i}{\partial K^2} \Delta K^2 + \ldots\ldots.$$

when higher terms are neglected this equation takes the form :

$$y_i(t,K+\Delta K) = y_i(t,K) + \sum_{j=1}^{n} \Delta K_j . S_j(t) \qquad (11)$$

It is then desired to compute the parameter changes ΔK so as to minimize the difference between the responses after the changes and the target responses $y_r(t)$. This is accomplished by substituting the expression for y_r given by equation (4) for all i, into equation (11) instead of $y_i(t,K+\Delta K)$. A quadratic system performance index is defined in the form:

$$L = \frac{1}{2} \int_0^{\infty} (y_r - y) \; Q \; (y_r - y) + (v_r - v) \; T \; (v_r - v) dt \qquad (12)$$

Where Q , T are weighting matrices and y_r , v_r are target responses to which it is required that the system outputs y and v should approach . The performance index L is minimized with respect to the parameter change K by differentiating L with respect to each of the parameter changes in turn and setting the derivatives to zero:

$$\frac{\partial L}{\partial K_j} = 0 \qquad \text{for } 1 < j < n \tag{13}$$

This process results in a set of n linear equations in the unknowns ΔK_j for all j, and these are solved to obtain values for all the parameter changes ΔK_j

The algorithm can be summarized in the following steps.

1- Start with a feedback parameter K corresponding to any flight condition .
2- Define small variations in flight condition parameters that retain system stability when any is occured.
3- Set flight condition parameters of the controlled system and create bands around these parameters(parameters $\pm$ variation).
4- Measure system flight parameters .
5- Compare the current flight parameters with the upper and lower limits of the band .
6- If flight parameters are located inside the band go to step 4
7- Apply a step signal with a size given by equation (3) on the controller reference.
8- Use equation (10) to calculate the sensitivity functions resulted from variation in flight parameters.
9- From equation (13) calculate the necessary feedback parameters variations.
10- Update the feedback parameters of the aircraft controller.
11- If the performance index L is minimized go to step 3 otherwise go to step 7.

EXAMPLE

The proposed technique is used to optimize the performancs of an aircraft control system under varying flight condition. The system is represented by equation (1). The elements of the matrix A are computed according to the flight coditions [6] while B is taken as [0 0 6.6667]. Five flight conditions are assumed. Each of which is imposed for a period of fifteen seconds. These flight conditions are tabulated below:

FLIGHT CONDITION	1	2	3	4	5
$Mach_0$	0.4	0.67	0.67	1.2	1.2
q_0	109	109	305	305	395

The parameter variations Mach and q are defined as 0.05 and 25 respectively. The responses of the proposed control system are illustrated in figure (1). These responses show that the system is stable for all assumed flight conditions.

CONCLUSIONS

In this paper a method, based on prameter sensitivity functions, for designing self adjusting digital control systems has been deecribed. This method does not require any parameter identification of the system except that of the controller. The method involves the use of parameter sensitivity functions for adjusting the parameters of an aircraft control system to follow the system dynamics. The technique is suitable for implementation on real world system.

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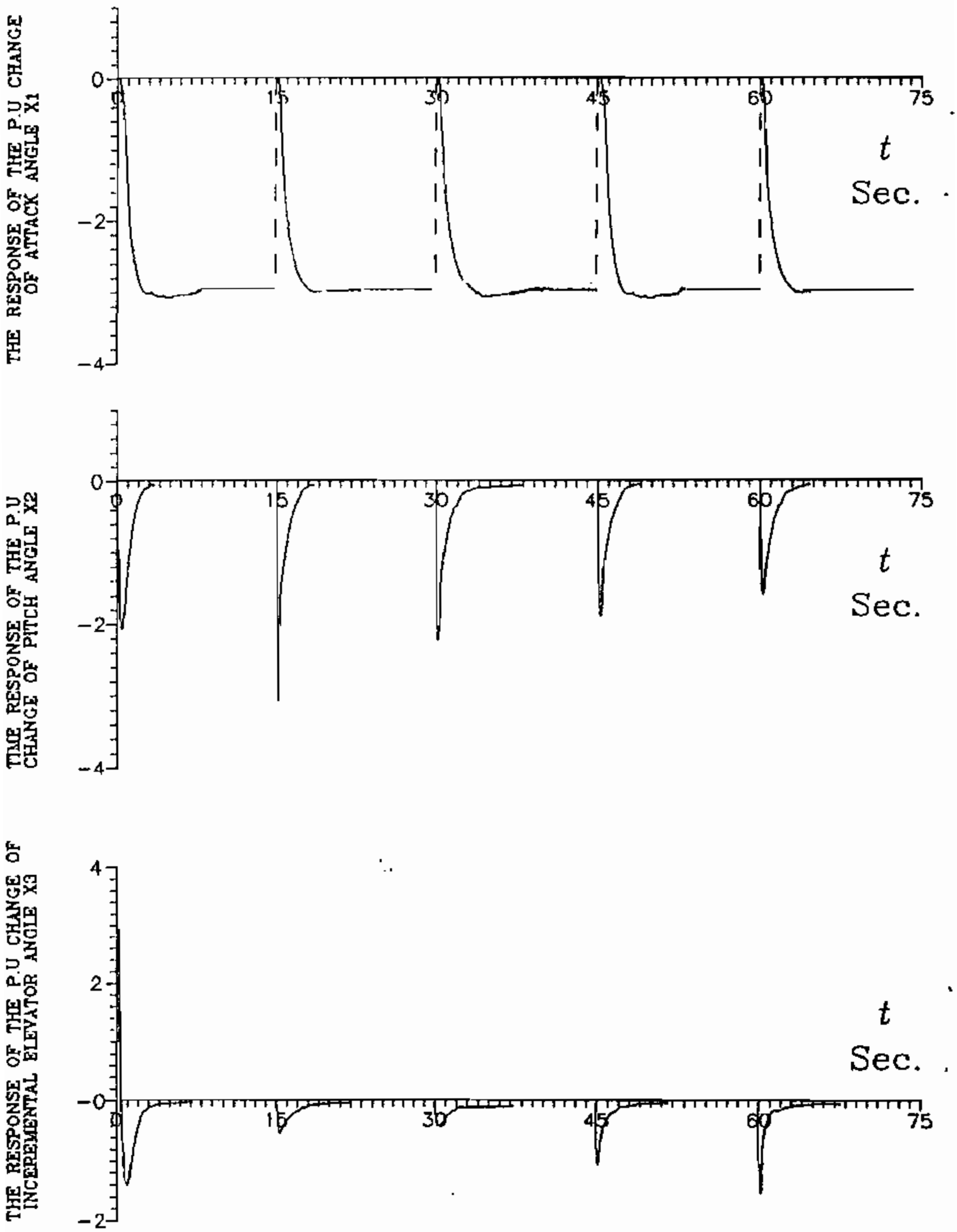

FIGURE (1): TIME RESPONSES OF THE CLOSED-LOOP CONTROL SYSTEM

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