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Modeling Pilot Control Behavior with Sudden Changes in Vehicle Dynamics

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A pursuit tracking model of the human pilot adapting to sudden changes in vehicle dynamics is developed and exercised. The current model is based upon a simplified representation of the human pilot in multi-axis tasks previously reported in the literature. A key feature of the adaptive model is the simplicity afforded by only varying two gain parameters in each control loop to accommodate pilot adaptation. The model is first exercised in a single-loop task in which the controlled element dynamics are changed from rate command to acceleration command (with time delay), back to rate command, and finally, to position command. A second example applies the model to a simple two-axis task (two control inceptors) in which the controlled element dynamics in both control loops are changed simultaneously. The model employed for sudden changes in vehicle dynamics is also applied to a single-axis task in which the controlled element dynamics change gradually over a 10 s period. Finally, longitudinal control of a simplified model of a fighter aircraft undergoing sudden damage is considered.

Nomenclature

C = command to position feedback loop in pilot model
CF1, CF2 = transfer functions of cross-coupling dynamics in two-axis tracking example
f = task interference parameter in two-axis application of pilot model
G_{nm} = model of the pilot's neuromuscular system
K_p = "position" feedback gain in pilot model
K_r = "rate" feedback gain in pilot model
K_{trigger} = trigger parameter in pilot model adaptation law
$M, \dot{M}$ = controlled element output and output rate
R = command to rate feedback loop in pilot model
t_c = "criteria time" at which controlled element dynamics change
x = signal in pilot model adaptation law
Y_c = controlled element transfer function
δ = pilot control input

Introduction

INTEREST in modeling the adaptive characteristics of the human operator/pilot began over five decades ago and continued into the mid-1970s, for example, [1–17]. Although interest waned in the intervening years, it has been rekindled by recent research in adaptive and reconfigurable flight control systems, for example, [18]. This renewed interest is attributable to questions that have arisen as to the ability of the human pilot to adapt to changing vehicle dynamics during and after the reconfiguration process. The research to be summarized has, as its goal, the development of a simple model for human pilot adaptation and the application of this model to a pair of control tasks in which sudden and significant changes in control system dynamics occur. A review of the research described in [1–17] is beyond the scope of this discussion. Such a review would, for the most part, merely echo the excellent summary provided in [13]. In contrast to these earlier modeling efforts, the approach to be discussed herein builds upon a simplified pursuit control model of the pilot that has been used in assessing degraded visual cues and vehicle handling qualities [19]. As such, the model is an extension of an existing structure that has been successfully used to describe human pilot control behavior in the absence of changing vehicle dynamics.

Background

The research summarized in [19] presents a control-theoretic procedure for modeling human pilot pursuit control behavior for flight control applications. Here "pursuit" refers to scenarios in which the human can discern system output from input, that is, more than just "error" information is available to the pilot. Figure 1 shows the model for a single-axis tracking task. Only two variables parameterize the model, the gains K_r and K_p, respectively, in the rate (r) and position (p) loops. The element G_{nm} in Fig. 1 represents a second-order model of the pilot's neuromuscular system,

$$G_{\mathrm{nm}} = \frac{10^2}{s^2 + 2(0.707)10s + 10^2} \tag{1}$$

Because of the manner in which the gain K_r is selected, the particular units on G_{nm} are of no consequence in the modeling procedure.

Table 1 shows values of K_r and K_p that yielded pilot models that conformed to the "crossover model" of the human pilot [20] for the variety of controlled elements indicated. The last element represents the "limits of manual" control for the pilot model in question. Figure 2 shows the resulting open-loop Bode plots demonstrating the crossover-model characteristics. The methods for selecting K_r and K_p are outlined in [19] and are based upon simple frequency-domain procedures. Hess [19] also demonstrates application of the model to multi-axis flight tasks. Hess [21] also demonstrates how these gains can also be selected from nonlinear simulation models of the vehicle being controlled.

It should be noted that the model of Fig. 1 and [19] differs from the structural pilot model discussed in [22] in a number of ways, but primarily in the absence of a proprioceptive feedback loop. In this light, the model of Fig. 1 involves some simplifications that will become apparent in examining open-loop pilot/vehicle transfer functions.

Adaptive Model

The fundamental hypothesis behind the adaptive model to be discussed is that the primary adaptation of the human pilot to changes in the vehicle dynamics occurs through selection of the inner-loop gain K_r. Changes in the outer-loop gain K_p are hypothesized to provide a vernier adjustment to improve system tracking performance. Changes in K_r are hypothesized to occur through sensed

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