N92-21477

SIMPLE CONTROL-THEORETIC MODELS OF HUMAN STEERING ACTIVITY IN VISUALLY GUIDED VEHICLE CONTROL

R. A. Hess
University of California
Davis, California

ABSTRACT

A simple control theoretic model of human steering or control activity in the lateral-directional control of vehicles such as automobiles and rotorcraft is discussed. The term "control theoretic" is used to emphasize the fact that the model is derived from a consideration of well-known control system design principles as opposed to psychological theories regarding egomotion, etc. The model is employed to emphasize the "closed-loop" nature of tasks involving the visually guided control of vehicles upon, or in close proximity to, the earth and to hypothesize how changes in vehicle dynamics can significantly alter the nature of the visual cues which a human might use in such tasks.

INTRODUCTION

The research to be briefly described stems from the author's participation in the Summer 1989 Workshop on the visually Guided Control of Movement, sponsored by the NASA Rotorcraft Human Factor Research Branch at NASA Ames Research Center. The approach to the Workshop theme discussed here is based almost entirely upon the human modeling paradigm which had its genesis in the work of feedback control engineers during, and immediately after, WWII [1]. The idea then, as now, was to compare the control behavior of the human to that of inanimate automatic feedback devices. The intervening 45 years has seen the discipline of manual control mature to the point that human performance, and to some extent, workload, can be predicted in certain well-defined control tasks with an accuracy sufficient for many problems of engineering design [2]. Based upon discussions at the Summer Workshop, the prevailing opinion among many psychologists is that the control theory paradigm has little more to tell us regarding human interaction with dynamic systems. This opinion may be premature.

A CONTROL THEORETIC MODEL FOR DRIVER STEERING BEHAVIOR

Automobile driving, or more appropriately, automobile steering, offers one of the simplest tasks involving human control of vehicle movement. The task is all the more attractive for discussion since it is one in which almost all humans above the age of sixteen participate daily. Figure 1 shows the steering task geometry involved in constant speed lane-keeping on a curving road. The variables

$y_v(t)$ and $y_R(t)$ represent vehicle and roadway lateral coordinates, respectively, and $\psi_v(t)$ and $\psi_R(t)$ represent vehicle and roadway heading, respectively.

A relatively simple control theoretic model for driver steering behavior can be offered as shown in Fig. 2 [3]. Space does not permit anything but a cursory description of this model. The interested reader is referred to [3]. Basically, the model is composed of high- and low-frequency compensation elements, defined by the transfer functions shown in Fig. 2. The high-frequency compensation is based upon a "structural model" of the human operator in which the compensation is achieved through proprioceptive, rather than visual, cues [4]. The low frequency compensation, denoted as G_C, is achieved through a simple visual guidance cue to be described shortly. It should be emphasized that, although nine parameters appear in the high-frequency compensation, all can be chosen based upon the vehicle transfer function $\dot{y}_v(s) / e_A(s)$ [3] and the dictates of the classical "crossover" model of manual control theory [5].

For the automobile steering task, feedback system design considerations dictate the form of $G_c(s)$ to be:

$$G_C(s) = u(s) / e_A(s) = K_Y(s) + (1 / T_3) \tag{1}$$

In the time domain, this transfer function translates into [6]:

$$\begin{aligned} u(t) &= K_Y\left[\dot{e}_A(t) + (1 / T_3)e_A(t)\right] \\ &= K_Y\left[(\dot{y}_R(t) - \dot{y}_v(t)) + (1 / T_3)(y_R(t) - y_v(t))\right] \\ &= K_Y\left[u_o(\psi_R(t) - \psi_v(t)) + (1 / T_3)y_E(t)\right] \\ &= K_Y u_o\left[\psi_E(t) - \tan(\psi_1(t))\right] \\ &\approx K_Y u_o\left[\psi_E(t) + (\psi_1(t))\right] \\ &\approx K_Y u_o \psi_U(t) \end{aligned} \tag{2}$$

where u_o is the vehicle speed (assumed constant, here).

The last of Eqs. 2 is interpreted in Fig. 3. The variable, us, in the driver model of Fig. 2 is synonymous with the angle between the vehicle x-axis, x_B, and the line-of-sight to an "aim point" on the tangent to the roadway, a distance u_oT_3 ahead of the vehicle. For most driving tasks, $t_3 \approx 3$ sec.

Using the driver model just described, very close agreement has been found between model responses and those obtained in driver simulation studies for a lane-keeping task on the curving roadway of Fig. 4 [3]. There is, of course, no psychological basis for the visual guidance cue just hypothesized. It may, in fact, not be a valid description for the actual visual field cue to cues used by the driver. However, the actual cues must, in a control theoretic sense, be equivalent to the cue just described.

A CONTROL THEORETIC MODEL FOR ROTORCRAFT NOE FLIGHT

Let us now consider that the vehicle shown in Fig. 1 is a rotorcraft in a nap of the Earth (NOE) mission in which the pilot is attempting to follow a groundtrack identical to the roadway of Fig. 4,m at the speed, u_o. As in the case of the automobile, we will consider only lateral-directional motion. Even so, the rotorcraft exhibits an additional degree of freedom, namely vehicle roll attitude ϕ. Now the same control theoretic model described in the preceding section for the high-frequency compensation can be applied to this problem, albeit with slightly different parameter values. Indeed, the same task variables and geometry as depicted in Fig. 1 are still valid. However, the fact that the vehicle dynamics have changed has a significant effect upon the form of $G_C(s)$ in the model. It can be shown that, in the case of the rotorcraft, the variable, u, is now given by:

$$u(t) = K_Y u_o \dot{\psi}_U(t) \tag{3}$$

thus, the time rate of change of the angle $\psi_U(t)$, or the angular velocity of the aim point line-of-sight is the visual guidance cue which can be hypothesized to be used by the pilot. Once again, there is no psychological basis for this cue, nonetheless, in a control theoretic sense, an equivalent cue or cues must be used by the pilot in this task.

CLOSURE

A simple control theoretic model of human steering behavior in a pair of vehicle control tasks with identical task descriptions has led to two different types of visual cues being hypothesized as central to successful task completion. The purposes of this admittedly rather crude study was to emphasize the fact that different vehicle dynamics can significantly alter the nature of the visual cues which a human might use in completing the task. This suggests that a study of the visually guided control of movement cannot neglect the fundamental feedback structure which permits such activity.

REFERENCES

[1] Weiner, N., *Cybernetics*, Wiley, New York, 1948.

[2] Hess, R. A., "Feedback Control Models" in *Handbook of Human Factors*, Ed: G. Salvendy, Wiley, New York, 1987, pp. 1212-1242.

[3] Hess, R. A., and Modjtahedzadeh, "A Control Theoretic Model of Driver Steering Behavior," *IEEE Control Systems Magazine*, to appear.

[4] Hess, R. A., "A Model-Based Theory for Analyzing Human Control Behavior," in *Advances in Man-Machine Systems Research*, Vol. 2, Ed: W. G. Rouse, JAI Press, London, 1985, pp. 129-175.

[5] McRuer, D. T., and Krendel, A., "Mathematical Models of Human Pilot Behavior," AGARDograph No. 188, Jan. 1974.

[6] Ogata, K., *Modern Control Engineering*, Prentice-Hall, Englewood Cliffs, NJ, 1970.

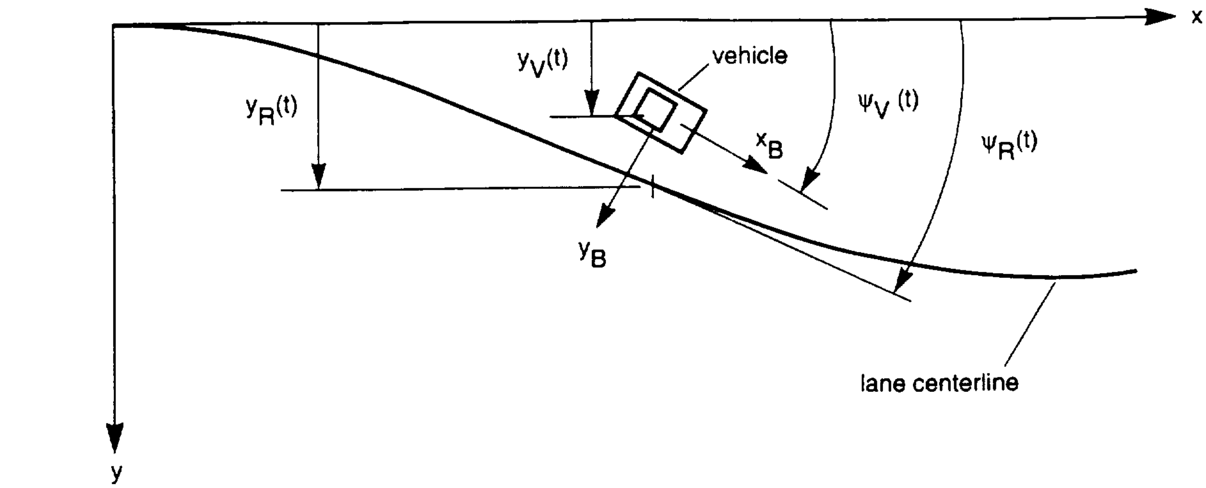

Figure 1. Steering task geometry.

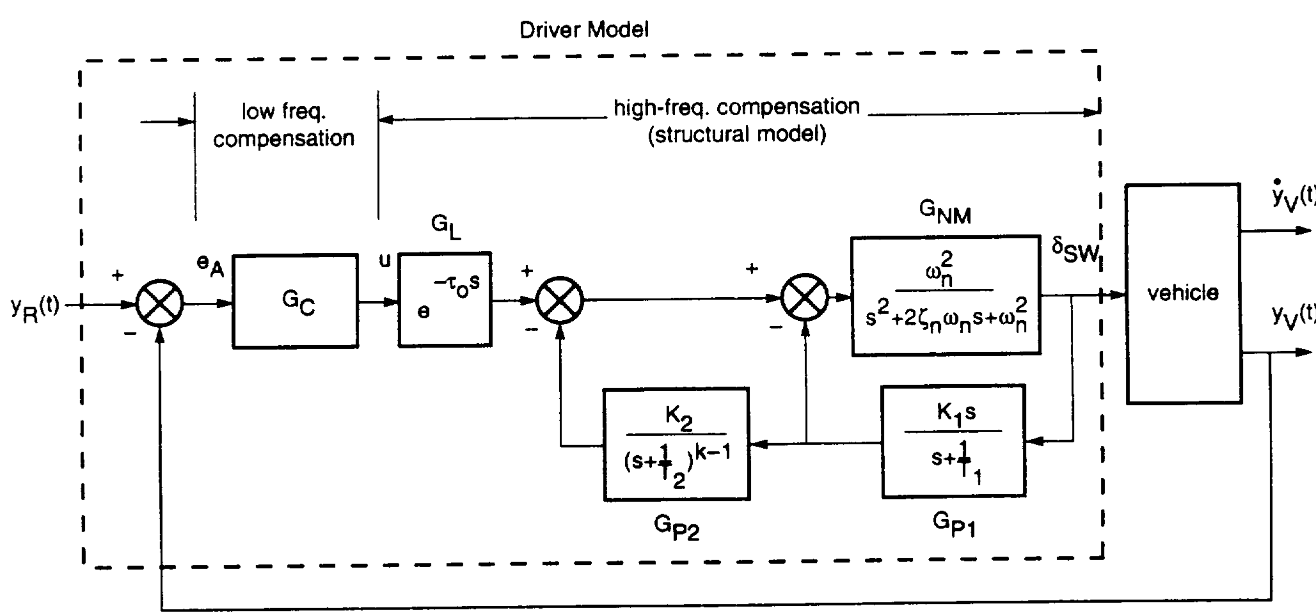

Figure 2. The driver/vehicle model.

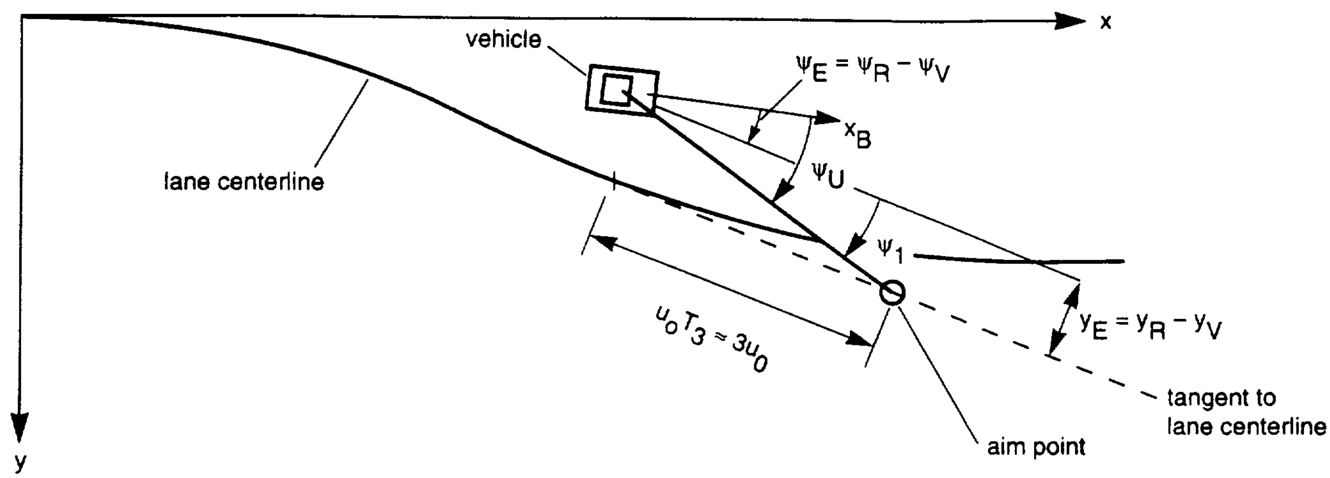

Figure 3. A visual guidance cue for the driving task.

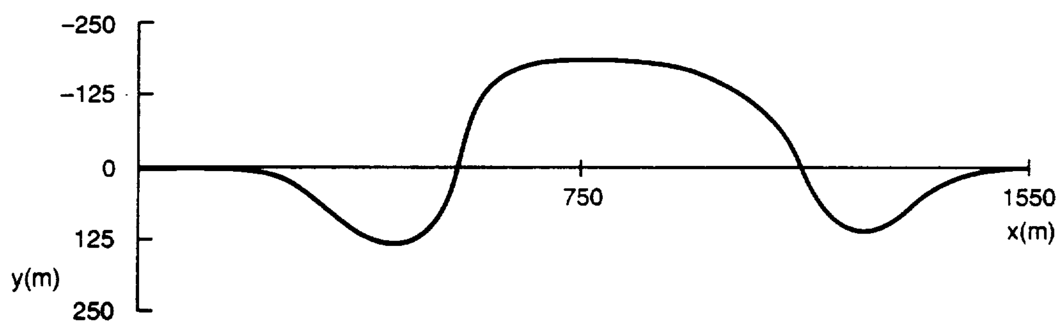

Figure 4. Curving roadway used in the driver simulation.