THE MODELLING AND CONTROL OF THE AGRICULTURAL SET DRIVER

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ABSTRACT

This paper presents a driver model based upon the control model of the human operator. Vehicle driven by operator may be considered as control system with driver as a controller and vehicle as controlled system. Driver efficiency depends on situation on the road, vehicle characteristic and psychical and physical driver features. The state space model of human operator formulation uses Pade approximations to model the time delays inherent in the human operator. Driver is included in road-vehicle driver system as feedback element. Parameters describing drives behaviour could be identified based on system model in frequency domain (from transmissibility) or in time domain (from correlation). The paper presents initial conception taking into consideration driver working in the tractor – agricultural machine set model.

Keywords: control theory, vehicle dynamics, vehicle steerability control, prognostic simulation

1. INTRODUCTION

Vehicle dynamics is one of the most important fields in research of motorization engineering. Running, acceleration, braking, changing of motion direction are typical dynamic processes. Quality of their execution depends on a driver.

Vehicle driven by driver may be considered as control system with driver as a controller and vehicle as controlled system. Driver efficiency depends on situation on the road, vehicle characteristic and psychical and physical driver features. From a linear input-output system viewpoint, the vehicle may be considered a generalized plant with the driver acting as the feedback control element. The driver regulates the system outputs (lateral velocity and yaw rate) in order to follow a desired roadway path. A main objective of the control of vehicle dynamics is to improve the handling performance, or maneuverability, in order to obtain safer and more joyful driving. Model is applied to tractor – potato planter set.

2. STATE SPACE MODEL OF THE HUMAN OPERATOR

Optimal control models of the human operator assume that the operator behaves in an “optimal" manner subject to human limitations.

The general vector-matrix form of the state space model for Multi-Input Multi-Output (MIMO) operator models with a mild restriction on the form of the dynamical model of the neuromuscular system is given by:

$$\dot{x} = Ax + B\delta + Ew$$

$$y = Cx + D\delta \qquad (1)$$

where:

$x(t)$ is a state vector composed of both plant and system disturbance states,

δ (t) is a plant input (is a vector of the operator inputs to the controlled element),

$w(t)$ is a disturbance vector modeled as a zero mean Gaussian white noise process with intensity W,

$y(t)$ is a output vector containing the parameters that the operator is trying to control (e.g. tracking error, error rate).

The modified optimal control models formulation uses Pade approximations to model the time delays inherent in the human operator.

There are as many Pade delays as there are operator inputs to the controlled element. The delays are placed at the operator's outputs and are considered a part of the plant dynamics for the purpose of synthesis. A second-order Pade approximation is chosen because it provides a very good approximation to a pure delay over the operator's frequency range of interest (approximately 0.1 to 10 rad/sec). Use of at least a second-order Pade approximation is assumed to be necessary to accurately model operator magnitude and phase compensation at the high end of the operator's bandwidth, such as the operator high frequency neuromotor resonant peak .

A second-order Pade approximation is given by (Doman 1998).:

$$\frac{u_d}{u_p}=\frac{1-\frac{1}{2}(\tau s)+\frac{1}{8}(\tau s)^2}{1+\frac{1}{2}(\tau s)+\frac{1}{8}(\tau s)^2} \tag{2}$$

where:

τ is the delay interval (in seconds),

u_p and u_d are the undelayed and delayed operator inputs to the controlled element, respectively.

In state space form, this can be expressed by:

$$\dot{x}_d = A_d x_d + B_d u_p$$

$$\delta = u_d = C_d x_d + u_p \tag{3}$$

where

x_d is a two-element vector of Pade delay states.

The undelayed operator inputs do not physically exist as measurable quantities but they are used as an intermediate step in synthesizing the operator model.
Augmenting the controlled element and disturbance with the delay dynamics yields:

$$\begin{bmatrix} \dot{x} \\ \dot{x}_d \end{bmatrix} = \begin{bmatrix} A & BC_d \\ 0 & A_d \end{bmatrix} \begin{bmatrix} x \\ x_d \end{bmatrix} + \begin{bmatrix} B \\ B_d \end{bmatrix} u_p + \begin{bmatrix} E \\ 0 \end{bmatrix} w$$

$$y = \begin{bmatrix} C & DC_d \end{bmatrix} \begin{bmatrix} x \\ x_d \end{bmatrix} + Du_p \tag{4}$$

or, with appropriate definitions,

$$\dot{x}_s = A_s x_s + B_s u_s + E_s w$$

$$y = C_s x_s + D_s u_p \tag{5}$$

You can easily convert any state-space model to transfer function form (Ljung and Glad 1994).

$$y(s) = C(sI - A)^{-1} Bu(s) \tag{6}$$

3. CONTROL MODEL OF THE HUMAN OPERATOR

The mathematical model of vehicle takes into consideration driver activity consists of two main parts: driver model and vehicle model (Doman 1998). The connections between road, driver and driven vehicle are shown on fig, 1. A set of mathematical equations in the analytical model is used to predict the important operating parameters of the vehicle's steerability (Schafer 2004). Identification of driver model parameters is achieved through an optimal control approach. (Zhaoheng 2007). Parameters describing drives behaviour could be identified based on system model in frequency domain (from power spectral density) or in time domain (from correlation).

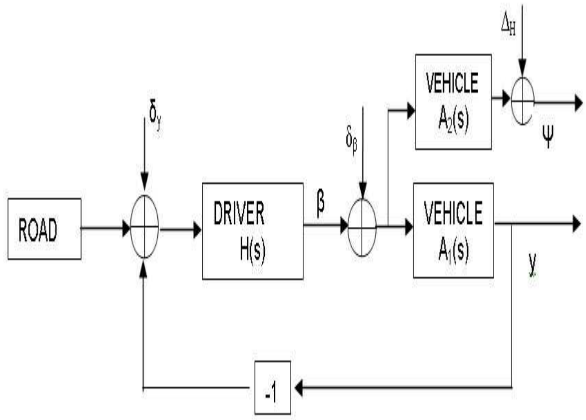

Fig. 1. Simplified diagram of road – driver -vehicle system with feedback

Steering angle β(t), vehicle yaw angle Ψ(t) and its lateral displacement *y* are specified by system of equation (7) (with initial condition *y*=0).

$$\begin{cases} \beta = H*\delta_y - H*y \\ y = A_1*\delta_\beta + A_1*\beta \\ \Psi = A_2*A_1^{-1}*+\Delta_H \end{cases} \tag{7}$$

It is possible to obtain dependences characterized transmittance H of driver model on the basis of above system of equation and spectral density and reciprocal spectral density of measured signals: $\delta_y{*}\,\delta_y^{*}$, $\delta_\beta{*}\,\delta_\beta^{*}$, $\Delta_H{*}\,\Delta_H^{*}$, $\delta_\beta{*}\,\delta_y^{*}$, $\Delta_H{*}\,\delta_y^{*}$.

The transmittance A_1 and A_2 are depending of physical parameter of the vehicle only. It is possible to estimate the transmissibility function or autocorrelation function of a driver depending on driver response time delay (τ) and constant parameters depending on driver's reaction time (Pawłowski 2008).

4. IDENTIFICATION OF DRIVER MODEL FROM EXPERIMENTAL DATA

The data used for system identification was collected from a series of in a typical operational condition driving scenario. The transmittances H and autocorrelations k of driver for different driver and vehicle way have been investigated.

The Power Spectral Density for steering angle β(t) can also be expressed as equation (8):

$$G_{\beta\beta} = G_{\delta_\beta}(1+b^2T_\beta^2\omega^2)/(1+T_\beta^2\omega^2)^3 \tag{8}$$

where:

$$b = T_\beta^{-1}(\tau + 3T_\beta + \sqrt{2}T_\delta)$$

The Wiener-Khintchine theorem states that the autocorrelation function is given by the Inverse Fourier Transform of the Power Spectral Density (PSD).
The autocorrelation function can be defined by:

$$k_{\beta\beta}(\theta) = \frac{1}{2\pi}\int_{-\infty}^{+\infty} G_{\beta\beta}(\omega)e^{i\omega\theta}d\omega \qquad (9)$$

An expression for the normalized autocorrelation function $\rho_{\beta\beta}(\theta) = k_{\beta\beta}(\theta)/k_{\beta\beta}(0)$ for steering angle β(t) is derived below (equation 10):

$$\rho_{\beta\beta}(\theta) = e^{-\left|\frac{\theta}{T_\beta}\right|}\left[1 + \left|\frac{\theta}{T_\beta}\right| + \frac{1-b^2}{3+b^2}\left(\left|\frac{\theta}{T_\beta}\right|\right)^2\right] \qquad (10)$$

Analysis of the control system was carried out using MATLAB analysis software. The optimization method was carried out for identification time parameters and reaction time delay τ from autocorrelation using Nelder-Mead simplex algorithm.

Figure 2 show the plots of normalized autocorrelation functions of steering angle β during field works for three different drivers.

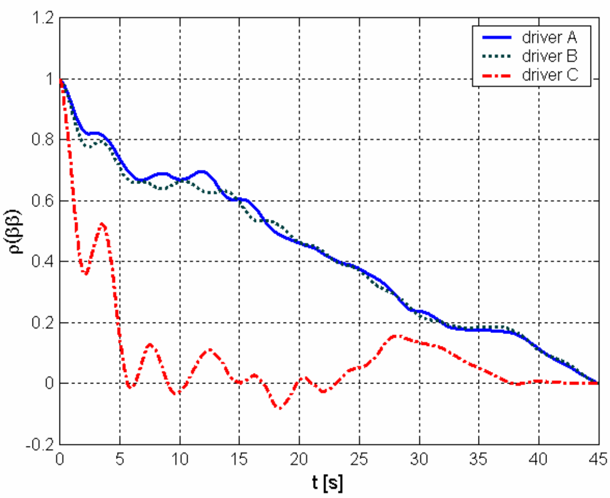

Fig. 2. Correlogram comparison for different drivers: A, B and C

Calculated for individual drivers reaction time τ using Nelder-Mead simplex algorithm was different. The driver reaction time for individual drivers ranged from 0.12 (driver A) to 0.43 (driver C) seconds.

5. PROGNOSTIC SIMULATION

After parametric identification we approach to research of system sensitivity influence on change of parameters with application of prognostic simulation methods.

An important element for project engineer is examining the influence of many design parameters like circles base, rigidity of tires and - the most important - driver perception of dynamic vehicle condition reception (e.g. gradient of acceleration of seat) and proper reaction of driver related with this.

6. CONCLUSIONS

The paper presents initial conception taking into consideration driver working in the tractor – agricultural machine set model. Vehicle driven by driver may be considered as control system with driver as a controller and vehicle as controlled system.

Parameters describing drives reaction time could be identified based on control system model in frequency domain (from trans-missibility) or in time domain (from correlation). Conducted tests proved that proposed model describes well tractor – potato planter combination steerability. The author is of the opinion that the model may be base for next research and specifying.

REFERENCES

Doman, D., 1998. *Projection Methods for Order Reduction of Optimal Human Operator Models*, PhD Dissertation, Virginia Polytechnic Institute and State University..

Ljung, L., Glad, T., 1994. *Modeling Of Dynamic Systems*, Englewood Cliffs, New Jersey, Prentice Hall.

Pawłowski, T., Kromulski, J., Szczepaniak, J., 2008. Influence of driver perception on safety of movement of agricultural machines, *XXI Conference "Problemy Rozwoju Maszyn Roboczych"*, 449-455, 21-24.01.2008, Zakopane.

Schafer, F.R., 2004. *Generalized Feedback Control and Application to Vehicle Path Following Control*, PhD Dissertation, TU Berlin.

Zhaoheng, L., 2007. Characterisation of optimal human driver model and stability of a tractor-semitrailer vehicle system with time delay, *Mechanical Systems and Signal Processing*, 21: 2080–2098.

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Dr. Pawłowski is also a designer of agricultural machines awarded in international fairs. For example, for device for opening the pair of side arms of the multisegment land of roller he achived a gold medal of The Belgian and International Trade Fair for Technological Innovation in 2007 and a silver medal of The 107^{th} International Invention Salon “Concours – Lepine” in 2008.

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