Verification of Structure on Model's Eyes – Hands During Signal Tracking

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Abstract— Future construction of cars requires knowledge about dynamics of driver's, because vitally affecting his responses to unexpected situations in traffic. Unpredictable situations in the driving of the car are real, because the traffic is crowded on the road. After detecting the models in the brain driver's, we could understand how models influencing his reaction on the traffic situations. Research results, supported by new advances in automation and information technology, can be used in the areas of so-called "intelligent systems to support decision of driver's" and "intelligent transport systems". This article explains a new conceptual model of driver behaviour, which is able to characterize the response of the driver in the car, from the "intelligent control system driver/car/traffic situation" point of view. In the paper the hypothesis is formulated, that immediate dynamics of driver's (delay, time constant and also controller structure), is create as sum of constant neuro physiological characteristics (muscles and nerves) and variable characteristics created in the brain. Variable characteristics are generating from "models of the traffic situations", which are continually adapted intra brain of driver's. The article outlined the verification of this model using description of measured reactions in real time. (*Abstract*)

Keywords—component; reactions measuring; real time; time delay; parameters identification (*key words*)

I. INTRODUCTION

Research of the manual control of the dynamic systems has its origin in the servomechanism theories from the 1945's. In subsequent years, several models of the human as a controller in closed-loop feedback control systems have been advanced [1], [2], [3]. In [4] the second order linear model with constant parameters describes real time measurements for eye-hand channel, and parameter identification with model verification. Experiments were realized as real time measuring of tracked input signals "with man" (unit step, sinusoidal and pseudorandom) and during verification of tracking "with model". This simulation experiments showed, that dynamics in linear models with constant parameters is not able to characterize human behaviour. Actual dynamic responses of human are variable in time. Identification algorithm [7] suitable for systems with variables parameters and identification experiments for linear model with variables parameters for driver's eye-hand channel, were described in [8]. There is also comparison of driver's reaction with responses of both models: linear with constant parameters and with variable parameters. In the model with variable parameters the driver's "dead time" (or

transport delay), supposed was as constant during identification.

Simulation experiments executed and described by author, have shown, that a key for describing the dynamics of driver behaviour are temporal variability of the "dead time" and "time constants". These parameters in the real driver behaviour are widely variable and have significantly influencing dynamic behaviour of the driver. Comparing of measured driver's reaction with simulation models responses, described in [9] showed that dynamic models with time varying parameters are able to characterise human behaviour better then model with constant parameters. But the identified variable parameters of the models varied in larger scale as a driver's muscles of the hands have physiological ability. Therefore is needed to study two problems [9]. First one is to find and verified such identification algorithm, which enables to detect variable parameters, of the driver's dynamics behaviour in eye hand channel. Second one is analyse the driver's control of the car, especially in the unforeseen (unknown) situations. In unforeseen situations reactions of driver's (time constants, variable dead time) essentially influencing dynamic of car and correct solution of traffic situation. In the [10] is shown, that changeable parameters in driver behaviour, can be explain by the help of new model, which take into consideration not only mechanical but also "psychological" and "intellectual" driver's ability. In this manuscript following hypothesis is described. The instantaneous measured parameters are combined from constant and changeable part. Constant part characterise dynamic of the muscles of the limbs and their neural connections. The changeable parts of parameters are generated intra brain of driver's. We can suppose that in the brain of drivers is a dynamic model, the hierarchical structure (generating of future continuation of instant situation), which contains "driver's, car and possible solutions of the traffic situations." This model we need by measurements reveal and mathematically describe.

The structure of article is as follows: Measurements for obtaining driver's responses are described in section 2. Section 3 contains new concept for interpretation of the driver behaviour on the higher than physical level by models. Section 4 contains results of simulation experiments an their interpretation fro hierarchical point of view. The paper ends with section 5, conclusion and outlook.

II. MEASUREMENT THE DRIVER'S REACTION

During measurements the "driver" track the signal $y_w(t)$, generated from the PC. Tracking this input signal is performed by moving the joystick (Fig. 1) or turning the steering wheel in such a way as to output signal $y_d(t)$ - (driver's reaction), followed the $y_w(t)$ with minimum deviation. Moving the lever in the range 0-60 [deg] is generated voltage signal 0-4 [V]. Pressing the button on the top of the lever starts experiment. Subsequent time instant of signal change from zero level, which we need to track, is randomised in the first third of the time scale.

Figure 1. Laboratory equipment, used for responses measurement

The signals were generated in form: unit step, step of velocity, step of acceleration, harmonic signal or pseudo-random signal. After the measurement finishes, the identification is done from measured data in off-line mode and verification by models described below. Typical step responses are shown in the Fig. 2. As can be seen, two different responses from the same "driver" are a little different, they cannot be repeated as the same responses.

Figure 2. Two measured step responses of the same driver

Figure 3. Model of the car driving

The driver's model for description of car driving is commonly considered according to block scheme on Fig. 3. Dotted line for car means that in this paper the motion of hand is considered as the output. The eye - hand channel dynamics essentially affects car - driver dynamic.

Next part of this section is focused on importance of the "delay" and "time constants" for understanding of driver dynamics and its location in driver's model. Questions about identification were discussed in previous author's papers. Both responses on Fig. 2, which are with overshoot, look like unit step response from second order transfer function with relative damping $a < 1$, which can be described by (1). It is certain, that driver which drives carefully generates response without overshoot, where relative damping is $a > 1$, which can be described by transfer function (2).

On the Fig. 4, can be seen example with time run of identified parameters and comparison of driver's with model response, for unit step input movement signal.

$$S(s) = \frac{K * e^{-D*s}}{T^2 * s^2 + 2aT * s + 1} ; a < 1 \quad (1)$$

$$S(s) = \frac{K * e^{-D*s}}{(T_1 * s + 1)(T_2 * s + 1)} ; a \geq 1; \quad (2)$$

Figure 4. Identification of driver reaction on step response

If driver drives curves or solves traffic situation, which is known from previous rides, he is able to predict development in traffic situation and suitability of own behaviour. Then appropriate model for driver's behaviour is transfer function with "predictive time constant" Tr described by (3).

$$S(s) = \frac{K(T_r * s + 1) * e^{-D * s}}{T^2 * s^2 + 2aT * s + 1} ; a < 1 \text{ or } a \geq 1 \quad (3)$$

$$S(z) = \frac{b_0 + b_1 * z^{-1} + b_2 * z^{-2}}{1 + a_1 * z^{-1} + a_2 * z^{-2}} * z^{-d_0} ; D_0 = \text{int}(D / T_0) \quad (4)$$

Transfer functions (1), (2) and (3) which describe continuous models of driver behaviour are four different structures, which depend on overshoot and predictive or non-predictive driver behaviour. From identification of sampled input/output data, we obtain only one structure (4), which characterizes driver behaviour in the discrete domain. Recalculation between continuous and discrete domain is described in [4] and is the part of identification procedures. Calculation of Tr time constant from (4), author of this paper derived in [8].

The range of drivers "delays" figured in [9] are informative, exact range can be obtain after response measurement. This are: delay of visual system (0.025-0.07 [s]), delay of central nervous system (0.05-0.11 [s]) and delay of synopsis system (0.02-0.05 [s]). In the equations, which describe driver behaviour, it is simpler to use only cumulative delay D (see equation (1)-(4)) instead of neuromuscular ($T1 \sim Tm$), error eliminating ($T2 \sim Tn$) and prediction ($T3 \sim Tr$), time constant. The equation and figures, which can describe driver error elimination and cross control, are described in [9] with more detail.

Time behaviour of identified varying parameters on the Fig. 6 for the model (3), shows two very important facts. First is, that "time delay" D , oneself removed, shortly after changing character of input signal (1.3 [s] - start of input signal as step of speed, 8.85 [s] - changing of input signal from step of speed to constant). Eliminating of time delay D can be seen more clearly on Fig. 5. The second "surprise" in the variability of the identified parameters is expressive increasing of parameter Tr in time instants, in which the error signal start increasing (see table with identified parameters on Fig. 6). Error means: input signal minus output signal - represented by hand movement.

For understanding and finding causality of varying time delay and varying time constants, the new hierarchical model of the driver behaviour was formulated and verified by simulation experiments. Its description is in the next section.

Figure 5. Tracking of the input signal "step of speed"

Figure 6. Response the signal speed following

III. HIERARCHICAL MODEL OF THE DRIVER

In the conceptual model on Fig. 7, some relations between psychological, intellectual's and physical properties for driver of car are depicted. Hierarchy and parts of the model, allowing understand the driver's during decision-making, as his interpretation for solving the traffic situation.

In the car has driver available information from "internal environment" -dashboards, and from the "external environment" -transport situation, and they are through the eyes obtained. Obtaining of information- this means also physical transformation of the controlled variable (position and speed of the car - as driven system) and the control variables (permitted speed, set point position for a car) in the "measuring parts" of the control system - car's driver. They have, after physical transformation in eyes, a type of physical variables, which the controller - driver, is capable to "handle". The driver's feet and hands, which forming "action part" of the controller-driver, representing the transformation of the power output" in the controller structure. Measuring elements - eyes, and action parts - hands and feet, are included in an part called the "interface" because by the help of them driver is "physically connected" with a controller - with brain and also physically is connected with controlled process - with the car. From the perspective of "quality" of control process is very important the dynamics of measured and action part of controller. Their dynamics is represent by the structures and constants in the differential equations, which we will measure. Put simply they dynamics can be characterize as "reaction time of driver in the car". These

constants cannot be never zero, although we can often "ignored" this, at design of control algorithm where are not taken into account.

The control loops which describe the driver's decision making in Fig. 7 shows, that signals which his eyes to handle, sometimes don't need to pass to the all control loops, notably not to the coordination and organizational level of consciousness. Often is adequate when are processed only at the subconscious level, at the level of "automatic" response. The road, after which the signal passes through, i.e. eyes, ocular nerve, brain, nerves into muscles and response of muscles, however, remains the same, is called "neuromuscular time delay from the external stimulus", and can not be from the response of driver removed. Although the "interface level" is a necessary part of the "driver -as the regulator", it is not part of the control algorithm and the time delays occurring in this part we cannot ignore but we have to take them into account in the process control. In terms of quality (effectiveness and success) of controlled process the "control algorithm" is the most important. In our case this means "the driver's ability", which are hidden in three levels: level of regulation, level of organization and level of coordination. The hierarchy levels "coordination level" and "organization level" are in play in external information processing during the so-called "steady state". In the steady state for already known traffic situation, the mentioned rules appear as "forecasting". This forecasting - prediction will be verified as part of a mathematical model of the driver's.

Figure 7. Hierarchy and links in the driver decision making response with interpretation of the traffic situations

IV. MEASUREMENT, IDENTIFICATION AND SIMULATION

In the next analysis of variability of parameters, it is needed to find influence of “driver's decision making” levels from Fig. 7 on the variability of parameters. We need to uncover, how we can from the course of parameters changes, deduce the properties in the driver's higher hierarchical levels. This is documented on Fig. 8, 9, by course of identified parameters for model for tracking of acceleration movement signal. Driver ahead knows that somewhere before end of measuring, target signal be going change from constant speed signal to signal of step. Driver's reactions should contain time constant Tr (prediction). On the Fig. 8 you can see very clearly how the predictive time constant Tr starts changing before expected change of input signal. At first, around 5 [s] Tr constant starts to rising and immediately following decreasing, follows next two changes of Tr .

This is the validation of hypothesis, described on Fig. 7 and (5), (6), that the input to the neuromuscular level is coming from the higher hierarchical levels of the driver's brain. Predictive time constant if has no changes, is coming probably from the regulation level, but instructions for changing Tr has to coming into the regulation level from coordination and organization levels, which is documented on Fig. 9 in more detail. This idea about structures of the driver's model on these levels are not know up to now. Description of one level of the assumed structures is described lower. The closed loop between “traffic situation” and hands (legs) through the mind is unquestionable. Then the first idea is controller (with variable parameters) in the closed loop. On the further experiments we can extend this idea by to consider the non-linear intelligent controller.

In this article, only first approximation of model for driver's decision making at hierarchical levels it is described, which means, that equation of “regulation level” is formulated and formally evaluated. The presumption is confirmed that generations of changing of parameters at

regulation level are generated at the coordination level after monitoring situation in organization level. The equation of structures and parameter's for the coordination level is on Fig. 9, but for organisation level were not formulated up to now. Immediately after new situation occurs, real error Er rising, negative delay Dm is active in the loop and controller parameters start to change so that eliminate Er . Further the Er is declines close to zero, prediction error Ep is generated and negative delay Dm is compensate over brain system positive delay Db , both are equivalent in the steady state.

Figure 8. Identification of response on acceleration signal

If can be derived equation as structure (3) from Fig. 9, which can explain changing of parameters in Fig. 8, this is verification the hypothesis about structure on coordination level. This can be seen in (5) which is equivalent to (3).

Figure 9. Details in regulation and coordination levels for the model of driver's behavior on tracking input moving signal

$$\begin{aligned}
S(s) \frac{1 * e^{Dm*s}}{(1/K)s+1} &= \frac{1 * e^{-Dm*s}}{Tm*s+1}; \quad Dm \sim Db \\
R(s) &= \left[r_p + \frac{r_i}{s} = r_p \left(1 + \frac{1}{T_i s} \right) \right] * e^{+Db*s} \\
\frac{Yd(s)}{Yw(s)} &= \frac{R(s)S(s)}{1+R(s)S(s)} = \frac{r_p(T_i s+1)}{TmT_i s^2 + T_i s + r_p T_i s + r_p} \\
&= \frac{1(T_i s+1)}{\frac{T_i Tm}{r_p} s^2 + \frac{T_i}{r_p} (1+r_p) s + 1}
\end{aligned} \tag{5}$$

The last transfer function in (5) is equivalent with (3) and is in accord with PI controller function: when integral gain r_i is decreasing, then integral time constant T_i is rising, and therefore an error Er is rising as can be seen at Fig. 5, Fig. 6 and Fig. 9. Only PI controller is without “prediction” and when we suppose PID controller then transfer function (6) for closed loop has still “second order” structure but is not purely dynamic. Is not derived equation for calculation of time constant, which is in numerator by second order Laplace operator from identified structure (4) until now. Closed loop structure (6) can better explain, while error Er and Ep can declines close to zero.

$$\begin{aligned}
R(s) &= \left[r_p + \frac{r_i}{s} + r_d s = r_p \left(1 + \frac{1}{T_i s} + T_d s \right) \right] * e^{+Db*s} \\
\frac{Yd(s)}{Yw(s)} &= \frac{r_p(T_d T_i s^2 + T_i s + 1)}{s^2(TmT_i + r_p T_d T_i) + s(r_p T_i + T_i) + r_p} \\
&= \frac{1(T_d T_i s^2 + T_i s + 1)}{\frac{T_i}{r_p}(Tm + r_p T_d) s^2 + \frac{T_i}{r_p}(1 + r_p) s + 1}
\end{aligned} \tag{6}$$

V. CONCLUSION

Simulation results showed that models with constant parameters for the driver eye-hand dynamics could be compared to human data qualitatively quite well only in case of tracking of unit step target signal. Therefore is more suitable operate with linear models which have variable parameters. Models with variable parameters are able to characterise driver's behaviour better. For study of interaction in driver/vehicle, especially in the unavoidable situations it is needed taking into consideration not only drivers “dead time” but also “time constants” of driver. This is reason for solving problems with measurement and identification of variable delays and time constant in driver's dynamics. This paper is focused on conceptual model of behaviour by driver/car interaction and verification of hypothesis that variable parameters are generated at coordination and organisation levels of driver's. On the base

of simulation experiments with model of driver's at regulation level as linear PI to PID controller with variable parameters, and this hypothesis was partly verified.

In further research it is needed to focus on identification methods applicable for flexible dead time and derivation of new predictive time constant from identified data of driver/car interaction. Using parallel computation methods by continuous identification of variable dead time, it will be possible to carry out also on-line identification of driver behaviour. Exact, certain and clear models for eye-hand, eye-leg channels are basic predisposition for building qualitative models of drivers' decision making in particular situation, planning of future activities and impact of instant reactions on development of future situations.

ACKNOWLEDGMENT

This contribution is prepared under the projects VEGA 1/1099/11 “Modelling and simulation of dynamical interaction in environment of driver/car/traffic situation

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