MEASURING AND MODELING THE DYNAMICS OF REACTIONS OF CAR DRIVERS

Mikulaš Alexík

University of Zilina, Faculty of Management Control and Informatics,
010 26 Zilina, Univerzitná 8215/1, Slovakia

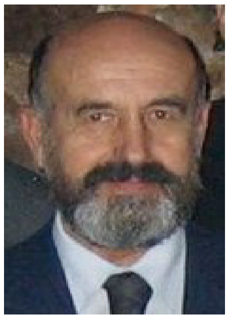
mikulas.alexik@fri.uniza.sk

Abstract

Future requirements of vehicle control dynamics especially the car, requires explore abilities of driver's in more detail. This research is motivated of possibility to apply potential of new automation's and information technologies on change control of vehicles towards a higher quality, called "making decision's with the aid of intelligent system driver&car". This paper describes possibilities for realisation of new conceptual models behaviour of driver’s and the levels of control in the intelligent control systems “driver/vehicle/traffic situation” and also conceptual simulator on verification (by measuring) for using of these conceptual models. Simulation experiments in the past made and published by author shows, that key parameter which described dynamics in driver behaviour’s is its “dead time,” or “transport delay”, which were assumed constant in simulation experiments but in real driver behaviour varies in large scale and substantially determine dynamics in behaviours of driver's. Some experiments with variable dead time in models of driver were made. In the paper it is illustrated the hypothesis, that immediate transport delay is probably created from constant time delay caused by the muscle of hand and its nerve connection, and variable time delay created in the brain. This variable time delay is probably generate by “models of the known traffic situations“, which are continually adapted in the driver’s brain.

Keywords: Measurement, Identification, Simulation, Driver, Car, Eyes/Limbs dynamics

Presenting Author’s biography



Mikuláš Alexík is a professor in the field of Information and Control Technics at the Technical Cybernetics Department, University of Zilina, Slovak Republic. He received his Ph.D. degree in Technical Cybernetics in Slovak Technical University, Bratislava, in 1980. His research interests include self tuning control algorithm, continuous identification of dynamics processes parameters, modeling and simulation of transportation means and processes, especially searching of optimal trajectory of underground vehicles and modeling and identification of driver in the car dynamics behaviors. He is worked a long time in national and international boards and societies (SSAKI, CSSS, ECCAI, IFAC, EUROSIM) and is member of the editorial boards of several journals. In the period 2007-2010 he was the EUROSIM President.

1 Introduction

Research on the manual control of dynamic systems has its origin in the servomechanism theories of the 1940's. In subsequent years, several models of the human as a controller in closed-loop feedback control systems [1] have been advanced [2], [3]. On model structure supposed in [1] for eye-hand channel, the paper [4] describes real time simulation experiments and parameter identification in this channel, for second order linear model with constant parameters. Simulation experiments were realized as tracking of input signals (unit step, sinusoidal and pseudorandom) by operator and operator's model. Simulation experiments documented in this paper showed that linear models with constant parameters are not able to characterize operator behaviour, whose dynamics is variable. These kinds of driver's models are used in simulation experiments, in which driver and car are connected in closed control loop [5]. Identification algorithm [6], which is more suitable for systems with variable parameters and also some identification experiments with linear model with variable parameters for operator's eye-hand channel were described in paper [7]. Some new simulation experiments with changeable dead time are described and interpreted in [8].

In this paper there is also comparison of the operator responses with responses on both linear models: model with constant and model with variable parameters. In the model with variable parameters the operators' "dead time" (delay) were supposed as constant during identification, because method, which would be able to identify variable dead time was not available. Simulation experiments documented in paper [7] showed that models with variable parameters are able to characterise operator behaviour better then model with constant parameters, but wide range in which the model parameters change, is a sort of disadvantage. Subsequently there arises a need to study two problems. First one is to find and verify such identification algorithm, which enables to detect variable dead time in operator's eye-limbs channels. This is not needed for operator models, which are simple. Second one is studying of driver/vehicle control especially in the unavoidable (emergency) situations in which operators' time constants as well as variable operators dead time have to be taken into consideration.

This paper describes possibilities for realisation of new conceptual models behaviour of driver's and the levels of control in the intelligent control systems "driver/vehicle/traffic situation" and then simulator on verification (by measuring) for using of these conceptual models. In the paper it is illustrated the hypothesis, that immediate transport delay is probably created from constant time delay from the muscle of hand and its nerve connection, and variable time delay created in the closed loop from Fig. 1 "outer situation - eyes – model for solving traffic situation embedded in the brain". In like manner is with predictive time constant in driver behaviour. Interpretation of the Fig. 1 it followed in the next part of article.

The structure of article is as follows: Interpretation of the conceptual models for the driver in the car behaviour is described in the next section. Experiments for obtaining driver's responses are described in section 3. Procedures for parameters identification in the driver dynamic model are shortly described in section 4. Section 5 contains results of simulation experiments, section 6 contains new concept for interpretation of the driver behaviour on the higher than physical level by models. The paper ends with section 7, conclusion and outlook.

2 Interpretation of hierarchic levels in the model of drivers

In this conceptual model are depicted some relations between psychological, intellectual's and properties physical for driver of car. Hierarchy and links of the driver's during decision-making response to the interpretation of the traffic situation are depicted in Fig. 1.

In the car has driver available information from "dashboards" (internal environment), and from the "external environment" (transport situation) this information is obtained mainly through the eyes. With the eyes it is performed the physical transformation of the controlled variable (position and speed of the car, car is the driven system) and the control variable (set point/permitted speed, set point position for a car) in the "measuring parts" of the control system (driver of car's) for such kind of physical variable which the control loop, i.e. the driver in car, are still to be capable "handle". They are: the position the clock hands of tachometer, or figure on board computer, speed and position of the car on the road or in the map navigator for controlled system - the car. The driver's feet and hands which forming "action part" of the controller (the driver of the car), representing therefore the "transformation of power output" in the controller structure. Measuring element - your eyes and action part – hands and feet, are in Fig. 3.1 included in an part called the "interface" because by the help of them driver of car's is "physically connected" to a control parts of car (which is, in terms of control circuit, called "regulatory body" and physically are connected with controlled process, in this case a car).

From the perspective of "quality" of control process is very important the dynamics of measured part and action part of controller. Their dynamics is characterized by the constants in the differential (differential) equations, which we will measure. Put simply this dynamics can be describe by "reaction time of driver in the car". These constants cannot be never zero, although we can often "ignored" them, which is reflected by the design of control algorithm where are not taken into account. The loops which describe the driver's decision making on Fig. 1 shows, that signals which his eyes to handle, sometimes don't need to pass to the all control loops and thus also to the coordination and organizational level of consciousness. Often is adequate when is processed at the subconscious level, 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, called "neuromuscular time delay from the external stimulus", can not be removed from the response of human. 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 can not ignore but we have to take them into account in the control process. Therefore the first task in this project is "measuring and processing (in models) response of driver to external stimuli in these channels: "eyes-hands", "eyes-feet" and cooperation "eyes-hands–feet”. From commented text is now clear that all responses are „response at the time ", and the possibility "to measure driver's response" to the nearest millisecond (detailed in the article) is a necessary requirement for hardware and software which for this action be used. This leads to requirements for specific hardware features and operating system (OS) PC, which can be used for measurement in real time.

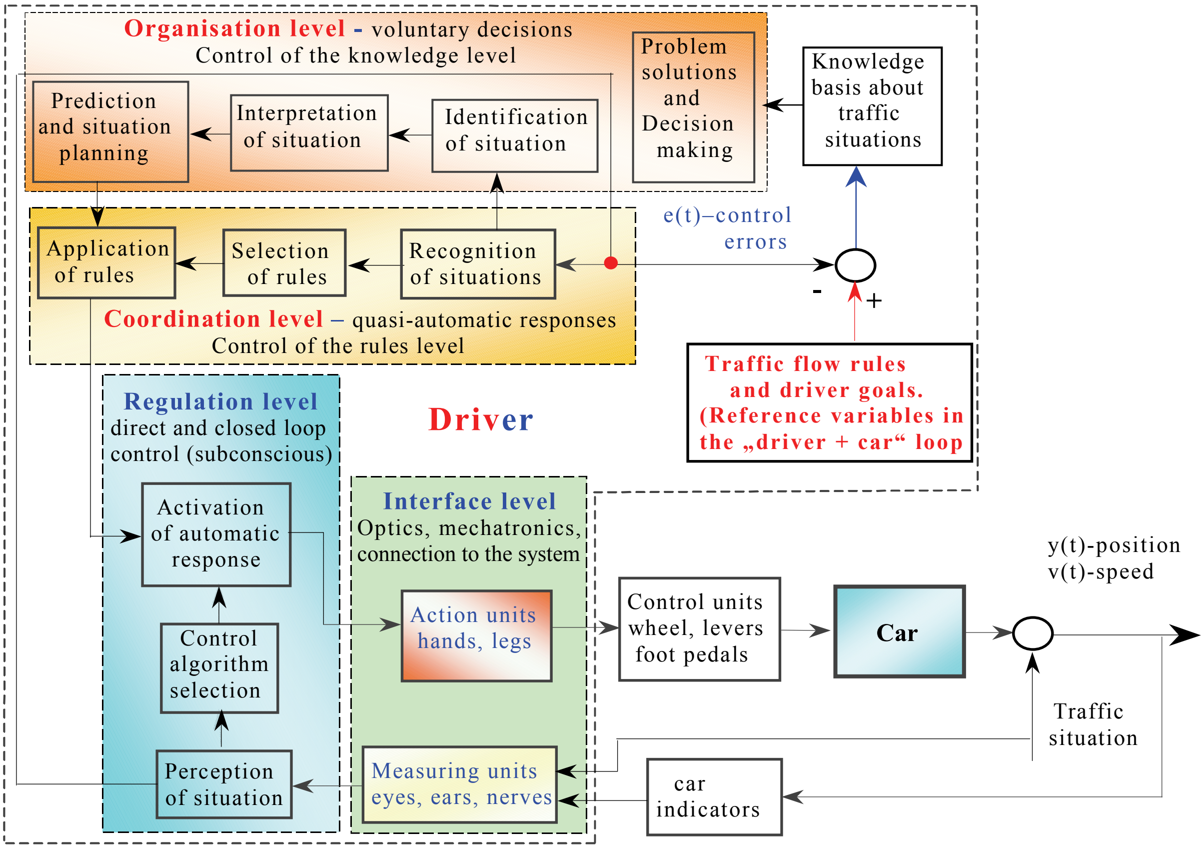


Fig. 1 Hierarchy and links in the driver decision-making response to the interpretation of the traffic situation

In terms of quality (effectiveness and success) of controlled process is the most important "algorithm of control ", in our case," the driver's ability:, which are hidden in three levels: level of regulation, level of organization and level of coordination. The levels of hierarchy "coordination level" and "organization level" entering into the external information processing during the so-called "steady state". Processing of information in them takes considerably longer than on the regulatory level and interface, but on the other hand it creates certain rules of conduct and knowledge base from which the subconscious (regulatory level) "automatically" obtained the necessary information about the reactions. In the steady state for already known traffic situation, the mentioned rules appear as "forecasting". This forecasting or prediction will be verified as part of a mathematical model of the driver of car's, which is described in this article.

For each driver of cars, is self-evident that with later survey of how the "need" to behave in a particular traffic accident it would be possible to avoided this. In immediate traffic situation is not possible to stop and reflect on how to deal with it. This can be done only on a computer's simulator and this solution from simulations to use for extension so called "knowledge base on traffic situations". The "models of situations" have each driver highly individual and "identification" of models "for these levels is theoretically and practically very difficult task. The simplest model is the "response time" more complicated is dynamic model of reaction time with variable parameters and the most complicated are separate models and reaction times for each level of the hierarchy. Generating of "traffic situation" can be implemented with varying detail with regard to the real situation. From a simple two-dimensional colour graphics on the PC screen to the complex 3D graphics projected with special projectors for the driver of car's. These goals will be solved later after proposed simulator will be constructed.

3 Experiments for obtaining drivers responses

During the simulation experiment the "operator" performs the tracking the signal *u (t)*, which is generated from the PC. Tracking the input signal *u (t* is performed by moving the lever (Fig. 2) or turning the steering wheel (Fig. 3) in such a way as to output signal *y (t)* (reaction of operator), followed the *u (t)* with minimum deviation. Moving the lever in the range 0-60 [deg] is generated voltage signal 0-4 [V]. The operator starts the experiment by pressing the button on the top of the lever. Subsequent change of signal from zero level to desired value we need to track is randomised in the first third of the scale. The signals were generated in form: unit step, time step, harmonic signal and pseudo-random signal. After the measurement finishes, the identification is done from measured data in off-line mode. Typical operator step responses and data for off –line identification are shown in the Fig. 4 where can be seen a random start of input target movement signal and differences in transport delay and responses between two operators.

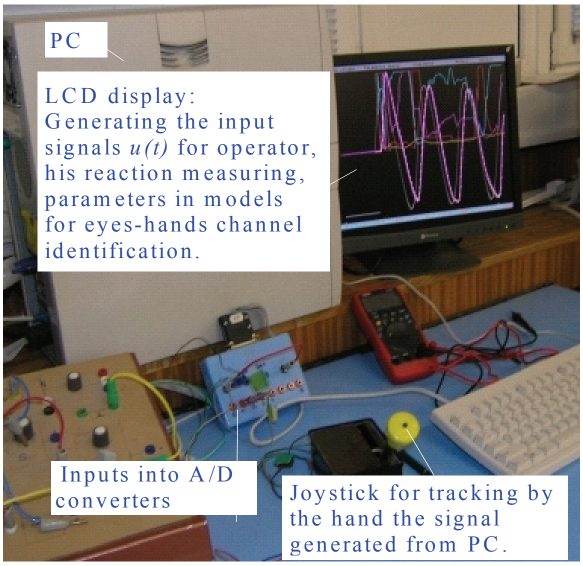


Fig. 2 Laboratory equipment for eyes-hands responses measurement

Fig. 3 Laboratory equipment G 25 for eyes-hands and eyes-legs responses measurement

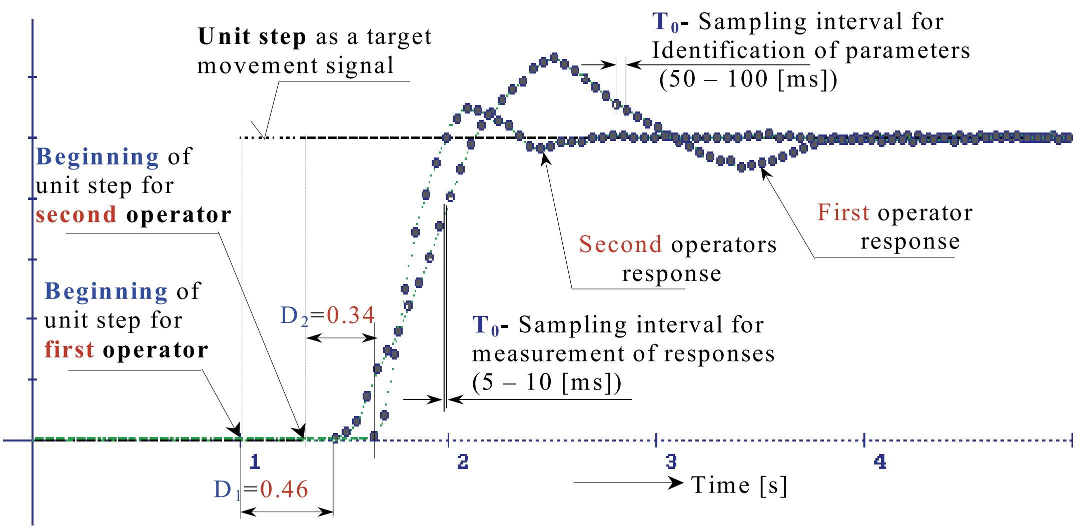


Fig. 4 Hierarchy and links in the driver decision-making response to the interpretation of the traffic situation

Both responses on Fig. 4, 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).

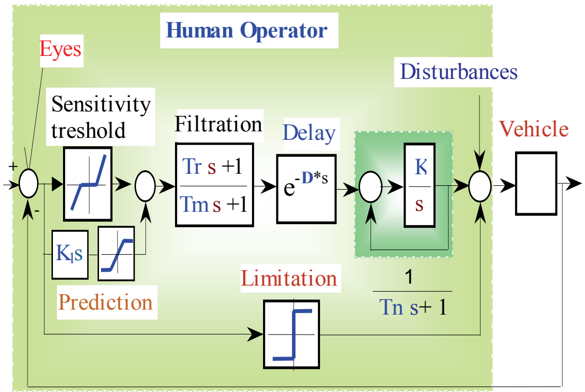


Fig. 5 Laboratory equipment for eyes-hands responses measurement

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

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

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 own behaviour. Then appropriate model for operator behaviour is transfer function with "predictive time constant" *Tr* described by (3).

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

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

Transfer functions (1), (2) and (3) which describe continuous models of driver behaviour have four different structures, which depend on overshoot and predictive or non-predictive driver behaviour. After identification of sampled input/output data, which represent driver behaviour, we can obtain one structure (4) only, which characterizes driver behaviour in the discrete domain. Recalculation between continuous and discrete domain is described in detail [4] and is also the part of identification procedures, which are characterized in next section. The range of drivers "delays" figured in [8] 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]), delay of synopse 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 (T_1~ T_m), error eliminating (T_2~ T_n) and prediction (T_3~ T_r), time constant. The equation and figures which can describe driver error elimination and cross control are described in [8] with more detail.

Car dynamics depend namely on car characteristics (mass, construction), which are constant and car speed, focusing point distance, traffic and weather situation which are variable and compensate with variable driver delay and time constant. If the weather or traffic situations are varying faster as can vary driver dynamics, then car dynamics is become an unstable (constant steer angle produce astatic – unstable response, nonlinearities as hydroplaning or lateral breakaway produce local instabilities) and come to accident. Therefore time constants T_r, T, T_1, T_2 and delays D, which characterise varying dynamics between eye and hands, eye and legs, are very important for the modelling the driver/vehicle interaction. This is the reason why to solve in detail problems with measurement and identification of changeable parameters in driver dynamics.

4 Identification procedures for obtaining parameters of drivers model

For parameter identification of the linear model for driver, two types of identification algorithms were used. In simpler case, it was a classical analysis of the step responses of first order and second order with overshoot (1) and identified parameters in transient function are constant. This analysis is described in [4]. In the second case, there are recursive least square (RLS) identification methods, namely the algorithms LDFIL, and REDIC [6]. These are necessary to apply for identification response on periodical, pseudo-random and constant speed target movement signal and also for step responses of transient function (2), (3) but can be used for arbitrary response. Advantage of RLS identification methods is that they can produce both constant and changeable parameters for linear transfer function. Disadvantage of these methods is, that sensibility on parameters variability depends from "forgetting factor", labelled as φ (forgetting of old input data). Forgetting factor (φ=1-constant parameters, φ < 0.98 variable parameters) is needed to set against star of identification procedure. Detailed information about forgetting factor and its adaptation in algorithm REDIC is [6] and [8].
One of problems in identification is, that all assumed models of operator (1), (2),r (3) after the identification has the same form (4) in Z-transformation. Relations for the recalculation of the parameters from discrete second order model (4) into parameters of continuous models (1) or (2) were described in [4] and [7].

Value “D” [s], in the models (1) to (4) is operator’s *dead time* and T_0 *[s]* in (4) means “sampling interval” for which is parameters in (4) computed from parameters of (1) to (3). Value of *Tr*- operator predictive time constant, is cardinal time constant, because implies that "traffic situation" is perceived in the “coordination” and “organisation” level of driver. This important “hypothesis” is documented in the next part of this article. In the situation when *Tr=0,* operator's behaviour can be described with models (1) or (2). If *Tr* is not zero than cannot be calculated only from parameters of denominator in (3), but also from numerator of (4) and sampling interval. Equations for calculation of *Tr* during identification procedure were derived by author and are described in [7] and [8].

The example of simulation experiment, comparison of measured driver output by tracking sinusoidal target movement signal with model output (for identified variable parameters) is described on Fig. 6. As can be seen on this figure, predictive time constant *Tr* is equal to zero in same part, or rapidly increasing in the other time parts. Very important fact is , that o*perator dead time D* are rapidly changes between times t_1= *5.6 [s]* (D_1*=0.225 [s]*) and t_2*=6.6 [s] (D2=0.07 [s])* The reason of this change can not be improvement in hand muscle dynamics but can be change on the input to the muscle from central nervous system, in the other words, control signal to the driver’s “regulation level” (see Fig. 1) or output signal from driver’s coordination level. Further analysis in time a behaviors of identified parameters of driver’s model enables us in the future “unmask” driver’s models on the coordination level and organization level.

At first but at least we need to formulate the structure of these models. This is indicated in the next part of this article.

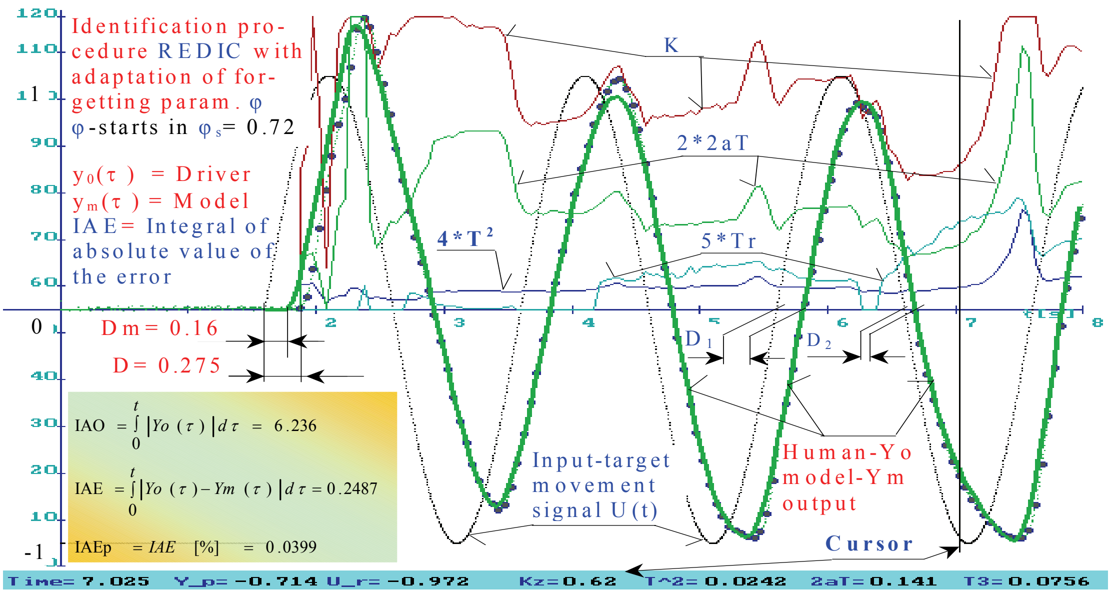


Fig. 6 Model with variable parameters compared to driver output by tracking harmonic target movement

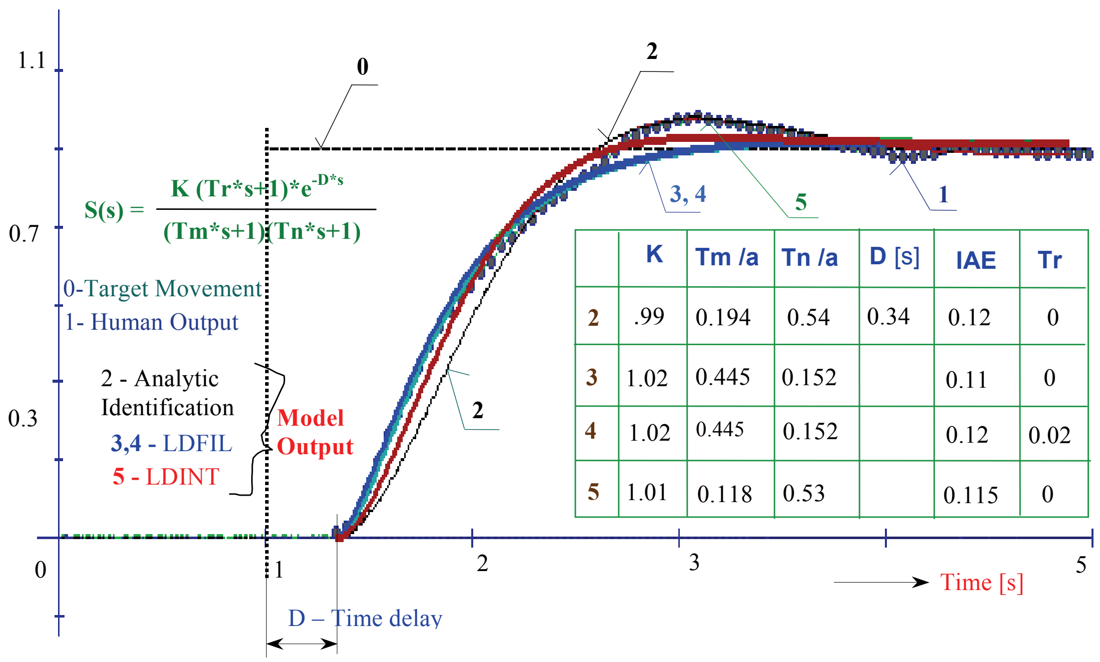
5 Simulation experiments results

For evaluation of experimental results of dynamics “eye-hand” of driver’s, the following parameters were evaluated: the dead time in the driver responses, time constants of the transfer functions (1),(3), integral of absolute value of an error (IAE) between operator and model response and structure of the model as the result of parametrical identification.

Typical examples of comparisons driver’s output with model output, when the outputs were generate by unit step target tracking, is shown in the Fig. 7 and Fig. 8. In Fig. 7 are presented several outputs for linear models with constant parameters, which differ by algorithm used for identification. As can be seen on Fig. 7 identification algorithms with assumption of constant parameters cannot do with calculation of parameters which are suitable for whole identification range. Therefore model with variable parameters can be more suitable.

To find appropriate model with varying parameters, it is needed to carry out more simulation and identification experiments to search for applicable model delay -Dm different from real delay of operator –D, which is changeable (see Fig. 6). Model delay -Dm is namely constant in used model with varying parameters. By application Dm=D can it possible to find out forgetting parameter "φ" with minimal IAE and the best tracking of operator's response. Advantage of REDIC algorithm is also adaptation of forgetting factor. Identification starts with φ_s and finishes with φ_e, and following experiment starts with φ_e. Disadvantage for parameters interpretation is, that varying parameters of the model vary in wide range (see Fig. 6, Fig. 8, Fig. 10).

In the next analysis of changeable parameters it is needed to find influence of “driver decision making” levels (higher hierarchical level –see Fig. 1) to change 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 can be documented on Fig. 9, Fig. 10, by course of identified parameters for model by tracking speed target movement. Driver ahead knows that somewhere before end of measuring, target movement be going to keep changing from constant speed to the constant step. His reactions should have contain prediction time constant *Tr*. In the model with constant parameters cannot be recognized this situation, because identified parameters will be changed briefly time before as expected changed of target movement happen. On the Fig. 10 you can see very clearly how the predictive time constant *Tr* starts changing before expected change of target movements. At first, around 7 [s] *Tr* constant starts to rising and immediately following decreasing, follows next two changes of *Tr*.



	K	Tm /a	Tn /a	D [s]	IAE	Tr
2	.99	0.194	0.54	0.34	0.12	0
3	1.02	0.445	0.152		0.11	0
4	1.02	0.445	0.152		0.12	0.02
5	1.01	0.118	0.53		0.115	0

Fig. 7 Models with constant parameters compared to driver output by tracking unit step target movement

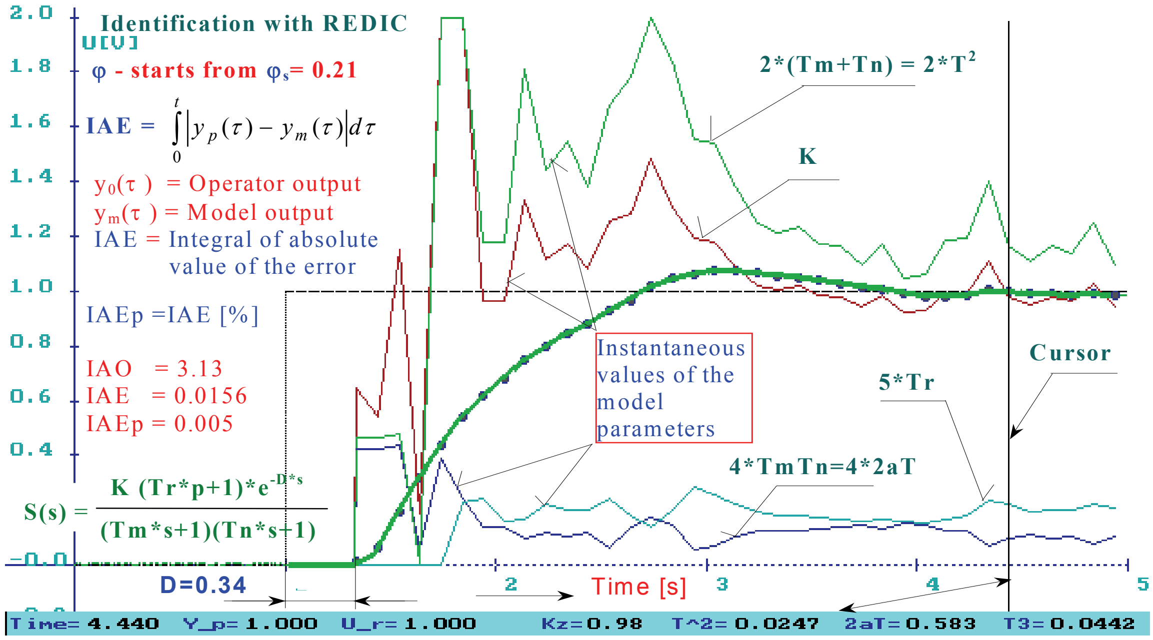


Fig. 8 Model with variable parameters compared to driver output by tracking unit step target movement

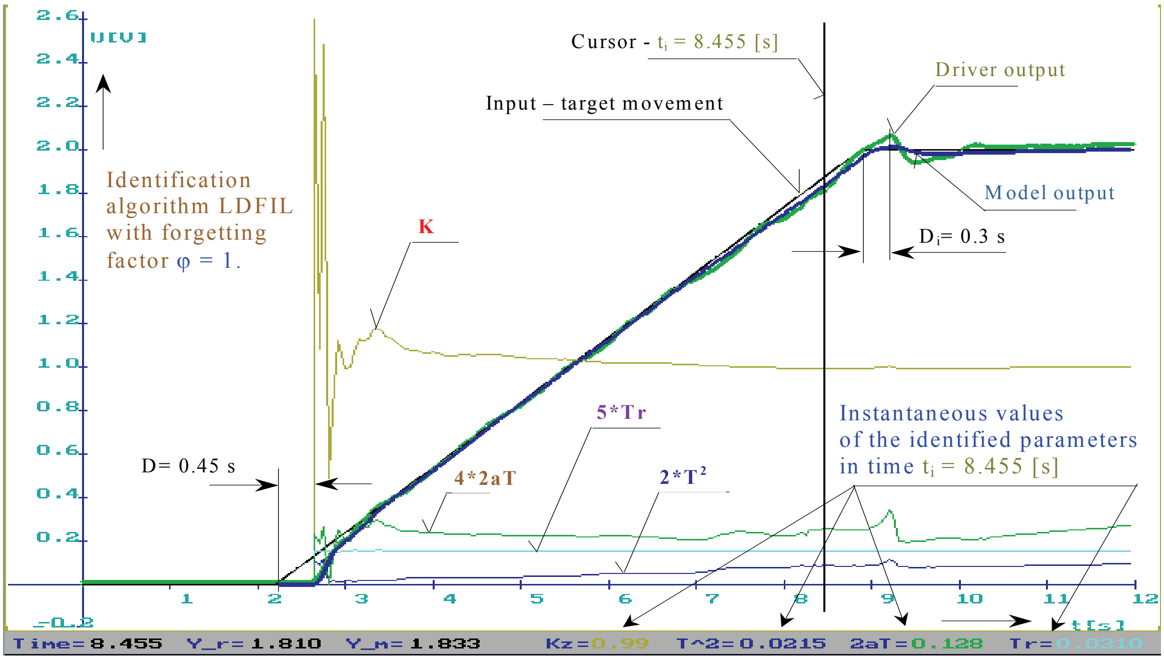


Fig. 9 Models with constant parameters output compared to driver output by tracking speed target movement

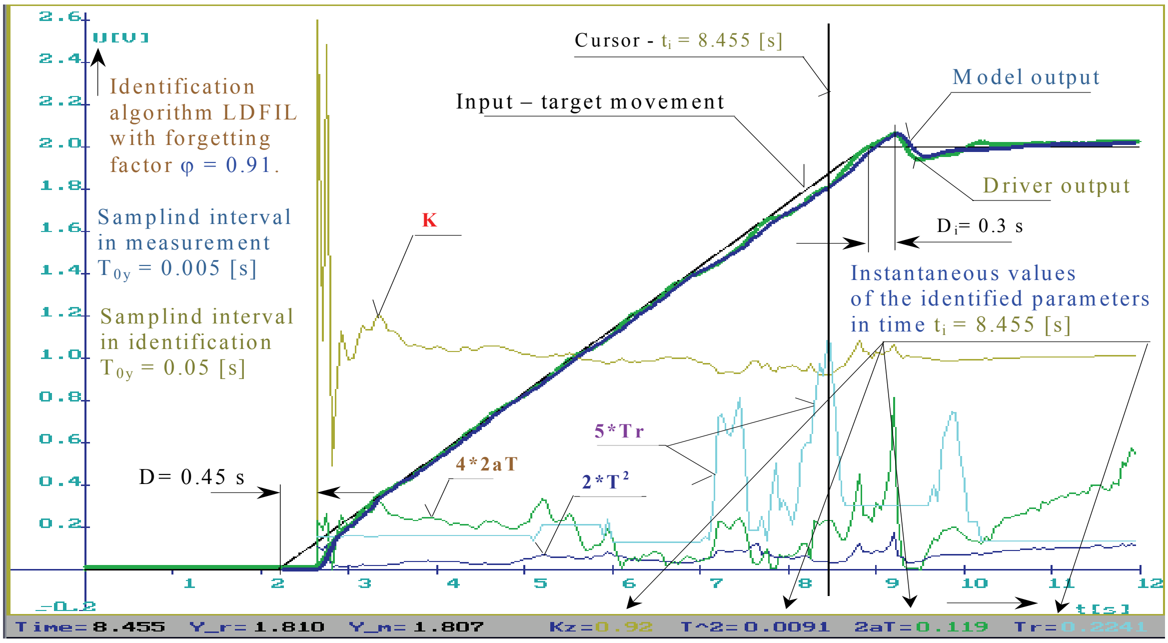


Fig. 10 Model with variable parameters output compared to driver output by tracking speed target movement

This is the validation of hypothesis described in the next section (see Fig. 11) that the input to the neuromuscular "level" is coming from the higher hierarchical levels in the driver's brain. Predictive time constant without changes on Fig. 9, is coming probably from the regulation level, but instructions for changing *Tr* have to coming to the regulation level from coordination and organization levels. The ideas of detailed structures of the models in these levels aren't know up to now. One of the assumed structures is described in the next section. The closed loop between "traffic situation" and hands (legs) through the mind is unquestionable. Than the first idea is controller (with variable parameters) in the closed loop. On the further experiments we can extend this idea to the nonlinear intelligent controller.

6 Model of the drivers Regulation and Coordination level

Basic block scheme for hierarchy and links in driver decision-making model was in detail interpreted in the section 2 and Fig.1. This basic model we need interpreted in more detail by equations, which can correct represent driver's dynamics, measured in experiments and described in previous section.

In this article only first approximation of models in driver's hierarchical levels for decision making is described, which means, that equation for "regulation level" are formulated and formally evaluated. Confirmed is presumption that generations of changes of parameters in regulation level are executed in coordination level after monitoring situation in organization level. The equation structures and parameters for organization and coordination levels are not formulated / known up to know. This structure is shown in Fig. 11. For interpretation of Fig. 10 it supposes that derivation and square derivation gains (time constant) are zero. Further we suppose that muscular system (negative) delay *Dm* and brain system (positive) delay *Db* are equivalent in the steady state.

The question is, if we derive equation with structure (3) and if acquired structure can explain changing of parameters in Fig. 10. Closed loop transfer function is described by (5) and is equivalent to (3).

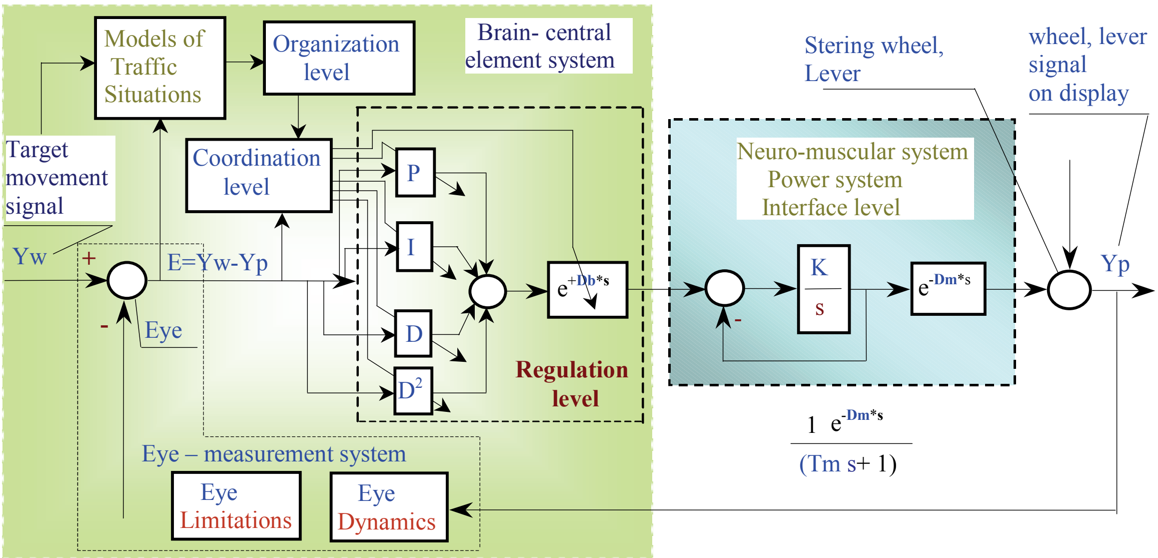


Fig. 11 Regulation and coordination levels in the driver's behaviour model by tracking moving target signal

$$S(s)\frac{1*e^{Dm*s}}{(1/K)s+1}=\frac{1*e^{Dm*s}}{Tm*s+1};$$
$$R(s)=r_p+r_i/s=r_p\left(1+1/T_i s\right)$$
$$\frac{Yp(s)}{Yw(s)}=\frac{R(s)S(s)}{1+R(s)S(s)}= \tag{5}$$
$$=\frac{r_p(T_i s+1)}{TmT_i s^2+T_i s+r_pT_i s+r_p}$$
$$=\frac{1(T_i s+1)}{\frac{T_iTm}{r_p}s^2+\frac{T_i}{r_p}(1+r_p)s+1}$$

Relative damping (6) can cause oscillating (Fig. 8) and damping (Fig. 10) responses in depending upon parameters in regulation level. Important is also, that total gain in (5) is equal one, as was measured in all simulation experiments. Where we till now supposed *predictive* time constant *Tr* now by (5) is equal *integration* time constant *Ti*.

$$T^2=\frac{T_iTm}{r_p};\quad 2aT=\frac{T_i}{r_p}(1+r_p)$$
$$a=\frac{\frac{T_i}{r_p}(1+r_p)}{2\sqrt{(T_iTm/r_p)}};\qquad a^2=\frac{T_i(1+r_p)^2}{4r_pTm} \tag{6}$$

In the Fig. 9, model with constant parameters we can suppose T^2 ~*(0.01-0.025)*, $r_p=1$, $Tr=0.031 \rightarrow Tm=0.5$. Then relative damping is (7) which very good meets all requirements. Increasing of *Tr* in Fig. 10 means increasing integration time constant *Ti* or decreasing

$$\text{if } r_p=1,\ Tm=0{,}5\ \Rightarrow a^2=\frac{4T_i}{4Tm}=2T_i$$
$$T_i<Tm\ \Rightarrow\ a<1\text{ ,oscilating response}$$
$$T_i=Tm\ \Rightarrow\ a=1\text{ ,oscilating border} \tag{7}$$
$$T_i>Tm\ \Rightarrow\ a>1\text{ ,damped response}$$

of integration gain in the times 7 [s], 8.4 [s], 9.9 [s]. And when integration gain is decreasing then driver's response cannot follow speed target movement without error. This interpretation is in order with simulation experiment in Fig. 10. The problem is that previous interpretations about predictive time constant were incorrect, because when integration time constant increases that mean the predictive time constant be on the decrease.

In the more extensive interpretations with more simulation experiments in the next article will be necessary taken into account also derivative and square derivative gain in regulation level for correct interpretation of predictive time constant.

The initial hypothesis, about variable delay and variable time constant generated from higher levels of driver's model we can, by simulation experiments and regulation level model, consider as correct.

7 Conclusions and outlook

Simulation results showed that the eye-hand driver dynamics models with constant parameters could be compared to human data qualitatively quite well only in case of tracking of unit step target movements. Therefore in future will be more suitable operate with linear models with variable parameters. Models with varying parameters are able to characterise operator's behaviour better but the wide range of the model parameter changes is a sort of disadvantage. For better study of driver/vehicle interaction especially in the unavoidable (emergency) situations it is needed taking into consideration not only drivers "dead time" but also all drivers' time constants. This is reason to solve problems with measurement and identification of variable delays and time constant in driver dynamics. This subscription is focused on conceptual model of behaviour by human/vehicle interaction and verification of hypothesis, that variable parameters are generated by coordination and organisation levels of driver's model. On the base of simulation experiments and model of driver's regulation level as linear $PIDD^2$ controller with variable parameters, this hypothesis were verified.

In further research it is needed to focus on identification methods applicable for varying dead time and on realisation of context and structure oriented level of behaviour in human/vehicle interaction. Using parallel computation methods for continuous identification of varying parameters and varying dead time, it will be possible to carry out also on-line identification of operator behaviour. Exact, certain and clear models for eye-hand, eye-leg channels are basic predisposition for building qualitative models of operators' decision making in particular situation, planning of future activities and impact of instant actions on development of future situations.

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