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Monitoring Driver - Vehicle Control in Automated Driving Applications

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Abstract: In the change from assisted to highly automated driving, the precise knowledge of the transition between “Driver Control Mode” and “Vehicle Control Mode” and reliable monitoring of driver vehicle control is of crucial importance. The central part is the modelling and identification of the driving behaviour. On this basis, adaptive functions leading to higher customer acceptance and therefore sustainable market penetration of ADAS and automated driving functions can be developed on the one hand. On the other, aspects of controllability affect the classification in terms of functional safety levels with regard to the validation in automated driving scenarios. The paper deals with three relevant aspects: objective monitoring of driver characteristics, adaptive function design using lateral control in lane keeping scenarios as an example and controllability, taking longitudinal control when following another vehicle as an example.

Keywords: *Intelligent/Automated Vehicles, Human Factors, Modelling of Driver - Vehicle Control, Functional Safety.*

1. INTRODUCTION

The consideration of the human-machine interaction for the evaluation of the closed-loop control stability is based on fundamental works such as [McRuer *et al.* 1965]. A first model of driver-vehicle control description was developed by [Bisimis 1977], but it has not been pursued further in terms of tests. The approach suggests an evaluation based on control theoretic stability criteria of the overall driver-vehicle system. It shows that the open control loop driver-vehicle always has a similar transfer function, independent of whether the vehicle is good or poor. This on the other hand means that different vehicle characteristics are reflected in the driver behaviour. A first general theory is derived from this: the evaluation of vehicles can be explained by the driver adaptation. [Apel 1997], for instance, also considers this by means of practically determined driver characteristics. Assuming a constant overall control performance, the driver model is adapted to different vehicles and speeds. The control parameters of the driver model and the known conventional vehicle criteria in terms of driving dynamics are analysed for correlations This shows a relation to the driver’s gain factor as well as to the driver’s rate time development anticipation and prediction).

Further analyses to verify the driver model and control loop requirements are given in [Apel 1997]. By means of the driving simulator test, the driver behaviour for normal driving and in a sudden critical avoidance situation is compared. The results show that the driver parameters (identical model structure of the lateral control) of each driving task vary depending on vehicle and speed. In the representation of the lateral control performance in the frequency range (fig. 1), the changes in the identified driver parameters are expressed as the quasi-constant overall system H_0 of the open control loop driver-vehicle for an identical driving situation. The drivers always adjust the characteristic stability variables, crossover frequency f_c and phase margin φ_R in a similar way. Significant differences result for both driving situations.

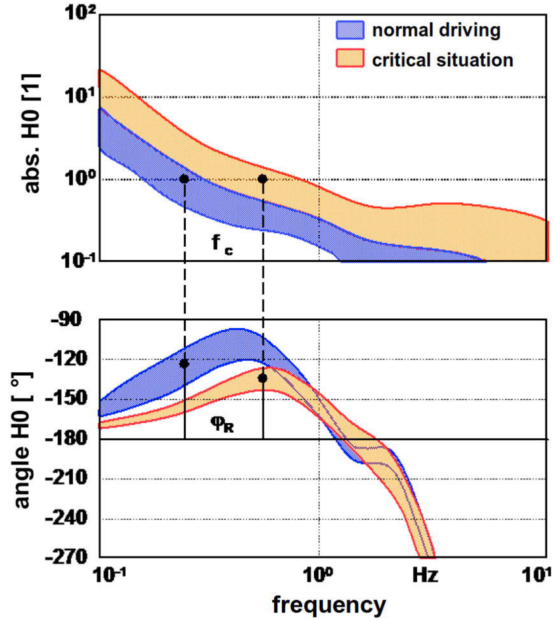

Fig. 1. Frequency behaviour of the lateral control in the bode diagram [Apel 1997]

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When comparing the frequency-response curve H_0 of ‘normal’ and ‘critical’ driving situations the crossover frequency curve rises and the phase margin is reduced. Altogether, the control remains stable, but the drivers have to act quicker in the ‘critical’ situation and closer to the stability limit. Thus, the motivation of the driver to adapt to different driving dynamics is confirmed and the influence of the driving task on the driver adaptation pointed out.

Based on further studies, the following results show how the identification of the driver control parameters can be used to specify the driver performance level (DPL) and for adaptive ADAS function design.

2. DRIVER-VEHICLE CONTROL MODEL

Within the conventional non-automated driving task the overall control-loop of driver-vehicle can be mainly characterized by the control behaviour of the driver, which not only includes the driving style, but in particular also the factors based on the experience and the age of the drivers. Typical features can be identified using lateral vehicle control, for example. Instead of alternative approaches, e.g. neural networks or fuzzy logic, a control theoretical driver model is used, that has been multiple verified amongst others in recently ongoing studies [Büyükyildiz *et al.* 2015]. Furthermore the description through transfer functions (cf. eq. 1-3) allows online parameter identification for real time adaptation applications.

As a basis the lateral driver model [Apel 1997, Henze *et al.* 2004] is considered, divided into a level of information processing and a level of control-technical elements. The control-theoretical model level is subdivided into a feedforward (anticipation) and feedback (compensation) component (fig. 2).

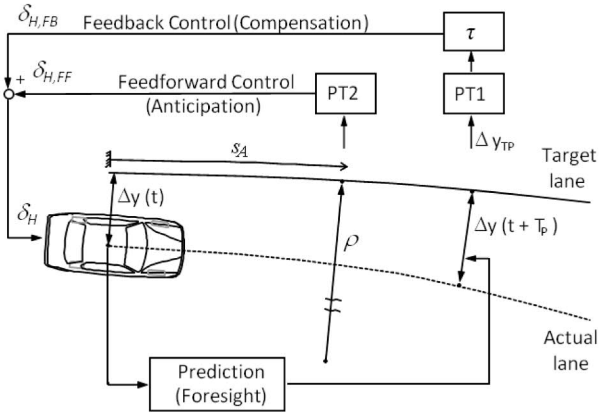

Fig. 2. Description of Driver-Vehicle Control Model

In the feedforward control mode (anticipation), the driver model sets a steering wheel angle based on the road curvature $\kappa = 1/\rho$ (eq. 1). In the feedback control mode (compensation), an additional steering angle due to the deviations Δy_{TP} of the actual course from the target course predicted at the prediction time T_P is considered (eq. 2). From the viewpoint of human control behaviour, the main driver parameters to be set are the gain factor V_{MR} (ratio of the steering angle and the deviation between the actual course and the target course) as well as the prediction time T_P.

Feedforward Control (1)

$$H_{FF}(s) = \frac{\delta_{FF}(s)}{\kappa s} = V_{FF} \cdot \frac{e^{T_A \cdot s}}{T_{Z2}^2 \cdot s^2 + T_{Z1} \cdot s + 1}$$

$$\approx V_{FF} \cdot \frac{\frac{1}{2} \cdot T_A^2 \cdot s^2 + T_A \cdot s + 1}{T_{Z2}^2 \cdot s^2 + T_{Z1} \cdot s + 1}$$

$$\Uparrow$$

ideal:

$$H_{VEH}^{-1}(s) = \frac{\delta_H(s)}{\kappa s} = \frac{v^2}{V_{\ddot{y}}} \cdot \frac{\frac{1}{v_f^2} \cdot s^2 + \frac{2 \cdot \sigma_f}{v_f^2} \cdot s + 1}{T_{Z2}^2 \cdot s^2 + T_{Z1} \cdot s + 1}$$

The adjustment of the parameters gain factor $V_{FF,}$ time of anticipation T_A and delaying time T_Z in the control model mainly results from the vehicle parameters.

The transfer function of the ‘compensating feedback control’ H_{FB} as a reaction towards course deviations or the steering angle regulation in ‘critical’ situations like obstacle avoidance or lane change manoeuvres, forms the

Feedback Control (2)

$$H_{FB}(s) = \frac{\delta_{FB}(s)}{\Delta y_{TP}(s)} = V_{FB} \cdot \frac{1}{T_{Z1} \cdot s + 1} \cdot e^{-s \cdot \tau}$$

Here, the driver parameter V_{FB} for the gain steering angle / lateral deviation, the time constants τ (dead time) and T_{Z1} (delay time) reproduce the delaying by information processing and the neuromuscular system.

The driver’s foresight qualities i e a forward-looking control behaviour part, are taken into account in an additional prediction function PR within the information processing domain.

Prediction (3)

$$PR(s) = e^{s \cdot T_P} \approx \frac{1}{2} \cdot T_P^2 \cdot s^2 + T_P \cdot s + 1$$

Considering a prediction time T_P out of the nominal-actual course values and the current vehicle condition, the estimated lateral deviation of a point lying ahead is calculated in the partial model prediction (eq. 3). This point marks the course fault of the vehicle at a future point in time $t+T_P$.

3. EXPERIMENTAL VEHICLES AND TEST SERIES

The driver model introduced in chapter 2 was implemented as a concurrent online algorithm and test series have been conducted with two experimental vehicles (fig. 3).