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SENSITIVITY INVESTIGATIONS OF THE LANE CHANGE AUTOMATED PROCESS

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Abstract: *The lane change automation is one of fundamental problems of vehicle control. In the paper we report selected fragments of our research, focused on sensitivity investigations of the controller. This controller is based on a simple reference model of the vehicle lateral dynamics with steering servomechanism inertia effects neglected. Sensitivity studies are implemented by comparative numerical simulations, with the real object (medium capacity semi-autonomic truck) modeled as a 3D multi-body non-linear system. Presented in the paper exemplary results demonstrate the effects of variations of the time constant parameter of the steering servomechanism. The results show the benefits of the vehicle's automated control for the lane change.*

Keywords: Lane change automation, Simulation, Modeling, Sensitivity investigations, Inertia effects.

1. Introduction

The lane-change maneuver is one of the basic vehicle's operations out of which sequences of complex maneuvers can be assembled (e.g., avoiding obstacles, vehicle passing). Therefore, this maneuver is a subject of many research papers related to vehicle automation (e.g. Bevan et al., 2010, Gao et al., 2010, Moshuk et al., 2013, Park et al., 2009, Shiller and Sundar, 1996).

Within our research project, analytical and simulation studies were undertaken on the application of the active steering system EPS (Electric Power System equipped with special controller) for automated driving of a semi-autonomous vehicle (truck of medium load capacity). Results of those studies were partially reported in authors' publications (Gidlewski and Żardecki 2015 a, b, 2016 a, b, Gidlewski et al. 2016). So far unpublished results presented in this paper involve sensitivity analysis of the controller action due to inertia effects neglected in the reference model (small time constant of the steering servomechanism).

2. Control system for lane change automation

The lane change process refers to two variables – the displacement of the centre of mass and the angular orientation of the vehicle body with respect to the trajectory of the centre of mass. According to the driving practice as well as the control theory, the steering system signal should have the "bang-bang" form, and the control process can be divided into two phases - transposition and stabilization (Fig. 1).

The steer in the first phase of the process can be carried out partially in an open system ("blindly", "quickly") by generating an appropriate profile of the steering wheel rotation angle. Accuracy of this phase of the manoeuvre should be ensured by the reference model. An additional correcting signal is present during this phase of control. Then, a correction of the steering wheel rotation angle is carried out in a closed loop system based on the principle of regulation, by comparing the displacement of the vehicle computed according to the reference model with its measured value. The steer in the second phase has to be carried out completely in the closed loop system, based on comparison of the angular orientation of the vehicle with respect to the roadway axis.

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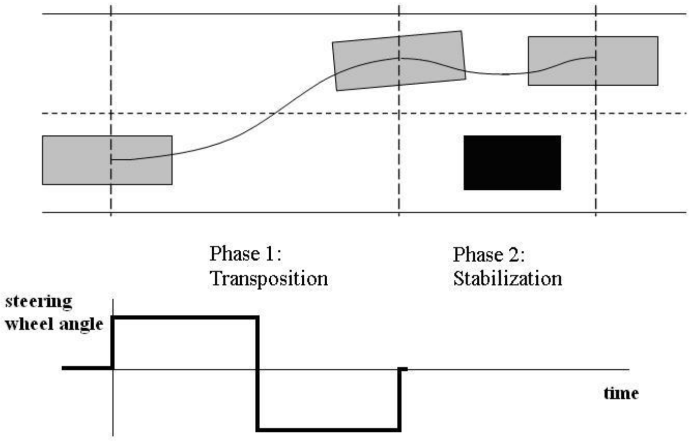
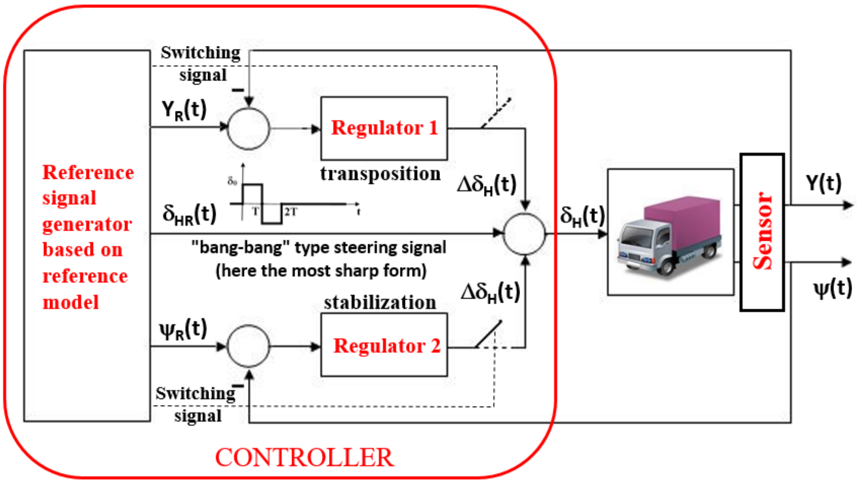


Fig. 1: Concept of time decomposition of the lane change control.

The controller (Fig. 2) generates the steering system signal $\delta_H(t)$ which is an input signal for the vehicle's steering system (EPS-type servomechanism). This input signal consists of the reference "bang-bang" type signal $\delta_{HR}(t)$ modified by corrective signals $\Delta\delta_H(t)$ from two regulators. Parameters of the reference signal generator as well as parameters of the regulators are based on the reference mathematical model of the lane change process. The reference model is a simplified linear dynamical model of the vehicle motion based on the well known "bicycle model" of vehicle lateral dynamics. For the analytical synthesis of the controller algorithm small dynamical inertia effects (producing small time constants) are neglected. Owing to such simplifications, the controller requires only several main vehicle parameters (speed, mass, etc). In practical implementation, the signal $\delta_H(t)$ has the limitation of its derivative (max 10 rad/s). Therefore, it practically assumes a trapezoidal form.



List of signs:

$Y_R(t)$, $Y(t)$ – reference / real lateral displacement

$\psi_R(t)$, $\psi(t)$ – reference / real angular position

$\delta_{HR}(t)$, $\delta_H(t)$ – reference / real steering signal

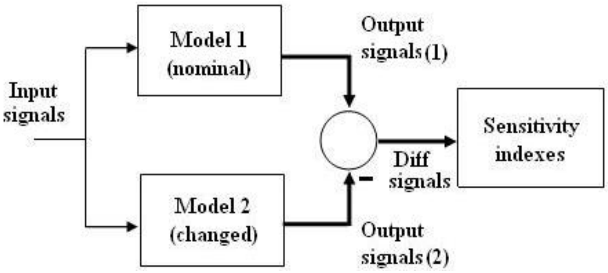
$\Delta\delta_H(t)$ – corrective signals

Fig. 2: Block diagram of the automatic control system.

Note that because of the inertia effects, the real steering signal acting on the steered wheels takes a smoothed form. Thus, the real steering signal $\delta_H^*(t)$ can be treated as the result of transformation of the signal $\delta_H(t)$ by a typical linear inertia block characterized by the time constant T. To analyze that effect on the control system action, sensitivity investigations are necessary.

3. Sensitivity investigations of the control system

In order to evaluate the performance of the control system, extensive simulations of the lane change process have been conducted with the use of a comprehensive model of the STAR 1142 medium truck (3D multi-body non-linear system) as a virtual plant to be controlled in accordance with the developed algorithms. The tests carried out to assess controller's sensitivity to various possible model inaccuracies have been performed in accordance with the schematic diagram shown in Fig. 3. In those tests, two simulations have been carried out for each case: one based on the nominal (initial) model and another based on the model modified by detuning its parameters, adding some disturbances, etc. Based on those simulation results, numerical indexes W_X are additionally introduced as relative sensitivity measures.



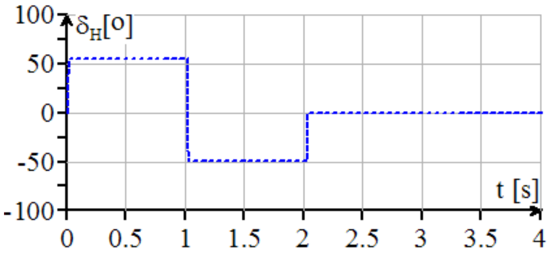
$$Wx = 100\frac{\int_0^{\tau}(x_1(t)-x_2(t))^2\,dt}{\int_0^{\tau}(x_1(t))^2\,dt}$$

$x_1(t)$ – output signal from Model1
$x_2(t)$ – output signal from Model2

Fig. 3: Block diagram visualizing the simulation tests for the sensitivity analysis purposes.

In the studies, when the subject of the sensitivity analysis concerns the time constant effect, the nominal model works with T = 0, while the modified model works with T > 0. For given T, the sensitivity indexes, especially $W_{\delta H*}$, W_Y, and W_ψ , express the effect and significance of the time constant.

Exemplary simulation results presented in Fig. 4 and indexes values demonstrate the effects of variations of the time constant on the lane change process. In this study, the vehicle (here fully loaded truck) was driven on a wet asphalt road (μ = 0.3) with the constant speed V = 70 km/h. For better understanding the role of regulators, the results are presented for the controller working without and with the regulators.



Controller without regulators *Controller with regulators*

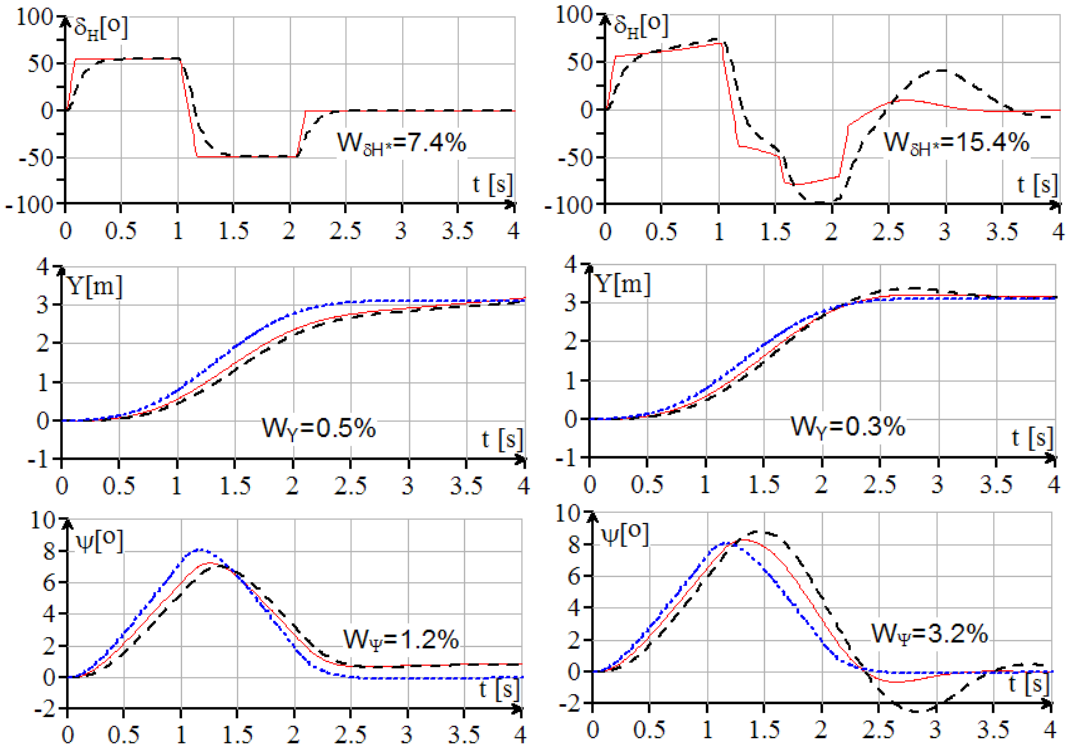


Fig. 4: Effects of time constant T variation.
Dotted line – for reference signals, solid line – when T = 0 s, dashed lines – when T = 0.1 s.

The values of indexes $W_{\delta H*}$, W_Y, W_ψ presented in Tab. 1 have been computed from the signals obtained for various conditions of vehicle motion (3 different speeds V, 3 different tire-road friction coefficients μ). In those studies the truck was loaded, and the controller was working with the regulators.

Tab. 1: Values of sensitivity indexes for various speeds and tire-road friction coefficients.

	$\mu = 0.1$	$\mu = 0.2$	$\mu = 0.3$
V = 16.67 m/s (60 km/h)	$W_{\delta H^*} = 10.8$ % $W_Y = 0.3$ % $W_\psi = 1.7$ %	$W_{\delta H^*} = 13.3$ % $W_Y = 0.3$ % $W_\psi = 2.4$ %	$W_{\delta H^*} = 15.3$ % $W_Y = 0.3$ % $W_\psi = 3.1$ %
V = 19.44 m/s (70 km/h)	$W_{\delta H^*} = 11.0$ % $W_Y = 0.3$ % $W_\psi = 1.8$ %	$W_{\delta H^*} = 13.6$ % $W_Y = 0.3$ % $W_\psi = 2.5$ %	$W_{\delta H^*} = 15.4$ % $W_Y = 0.3$ % $W_\psi = 3.2$ %
V = 22.22 m/s (80 km/h)	$W_{\delta H^*} = 13.0$ % $W_Y = 0.3$ % $W_\psi = 2.0$ %	$W_{\delta H^*} = 14.3$ % $W_Y = 0.2$ % $W_\psi = 2.5$ %	$W_{\delta H^*} = 15.2$ % $W_Y = 0.2$ % $W_\psi = 3.2$ %

4. Conclusions

The results of simulations and the sensitivity analysis show that:

- The regulators are necessary for the proper operations of the controller.
- The algorithm of the controller with regulators functions well even with the small inertia effects of the EPS steering system neglected.
- The algorithm of the controller with regulators operates well for various conditions of vehicle motion.
- The method of automatic control of the lane change manoeuvre based on the controller equipped with regulators can be an attractive idea for developers of active steering systems that enhance active safety of cars and trucks.

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