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SIMULATION OF DRIVER BEHAVIOUR IN CORNERING MANOEUVRE

[1]Preda, Ion*, [1]Vulpe, Viorel, [1]Enache, Valeriu

[1]"Transilvania" University of Brasov, Romania

KEYWORDS

steering process, handling, driver behaviour, computer simulation, experiment

ABSTRACT

The traffic active safety is directly influenced by the drivers' actions. In this circumstance, to understand the way that the driver judges and reacts in normal or extreme situations can be vary useful for the traffic safety responsible factors: vehicle manufacturers, road constructors, drivers, transportation staff.

This document proposes a computer model that contains two feedback circuits (one for the touch sense, turned on by the un-commanded steering wheel rotation, and other for the visual sense, initiated by the deviation from the trajectory) and an anticipative module, based on the driver experience. The driver actions are transferred as inputs to a sub-module which determine the current car kinematics. The car response is computed considering possible perturbations as wind gust, road inclination, effects of tractive or braking forces.

Changing the model parameters (gain, reaction time, anticipation distance), the behaviour of different driver types was simulated.

Data records, obtained from sensors in different road tests, were used for model validation. The good concordance between theoretical and experimental results demonstrates that the model can be used to simulate the handling behaviour of the vehicle-driver system.

MAIN SECTION

INTRODUCTION

The driving process consists in the control of the speed and position of the vehicle during the travel. If the speed is regulated by the help of propulsion and braking system, the desired position of the vehicle obtains mainly using the steering system and is characterised by the trajectory of a certain point on the vehicle longitudinal axis, the “directing point”, and by the longitudinal vehicle axis position in respect to the trajectory, the “sideslip angle”.

The handleability of a vehicle represents the sum of qualities that characterises the possibilities to modify his travelling direction and directing point trajectory in concordance with the driver intentions. To be handleable, a vehicle must have a stable movement. Characteristics influencing handling reveal by vehicle reaction to commands and perturbation.

In literature, most models simulating the driver comportment consider the driver as a controller with one feedback circuit (3, 4, 10, 12), which generally is sufficient for many study types. The system to be controlled is the vehicle that generally has as input value the steering wheel angle and as output value deviation for the linear trajectory. In majority of cases, the vehicle model is simple (the so-called “single-track” or “bicycle”), that uses one equivalent wheel for each axle and disregards the effects of roll movement.

Other studies (5) use a more complicated model with two feedback circuits, approaching better to the human comportment. Inner circuit, subordinate, is “haptic” (considering the driver’s information obtained by the touch sense from the un-commanded steering wheel rotation) and outer circuit, governing, is “visual” (initiated thru the visual sense by the deviation from the trajectory).

Other important component of the driver steering actions is represented by anticipative behaviour (1, 3, 4, 10, 11, 12) which, based on his experience in traffic and on vehicle knowledge, permits him starting faster the controlling actions.

DRIVER MODEL

This document proposes a computer model that contains both control levels, visual (fig. 1) and haptic (fig. 2), and also an anticipative module.

This study’s controlled vehicle is a medium car, for which was designed and tuned a Matlab-Simulink model (2), an extension of the basic “bicycle” model, that is able to include new influences for steering, traction and braking systems. This appears in figure 2 as block **Vehicle** and determines the current car dynamics and kinematics.

Even this model can deal with variable driving speed, for this study the speed will consider constant and is an input value, v, for the block **Vehicle**. The driver action is transferred also as other input – the moment applied to the steering wheel *Msv*. The car response is computed considering possible perturbations (as wind gust, road inclination, effects of tractive or braking forces) and is appreciated by tree output state-variables: real steering wheel angle *Aswr*, course (yaw) angle ψ and sideslip (float) angle β of the centre of gravity. The sum $\psi+\beta$ represents the heading angle and gives the car orientation in a fixed coordinates system.

For the haptic control circuit (fig. 2 and block **TouchControl** in fig. 1), the input is the desired angle *Aswd* of the steering wheel. This convert in a certain moment applied to the steering wheel as function of driver experience, temperament and car knowledge and accommodation. This angle-moment transformation function is considered as constant-gain amplification (block **TouchGain** in figure 2). The gain value can differ for driver to driver and also for the same driver at different moments in time.

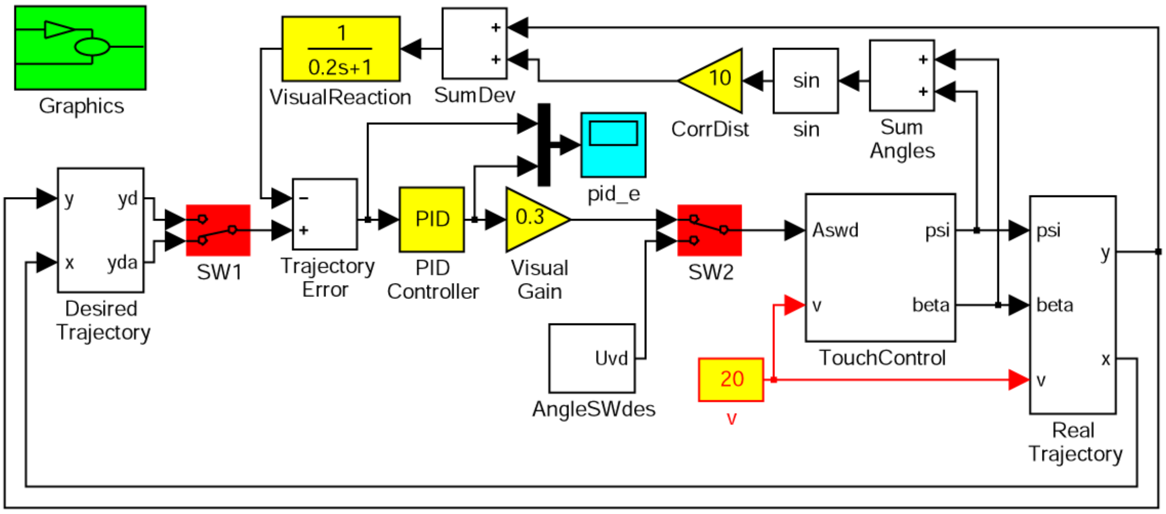

Fig. 1 Visual (outer) feedback circuit of driver model

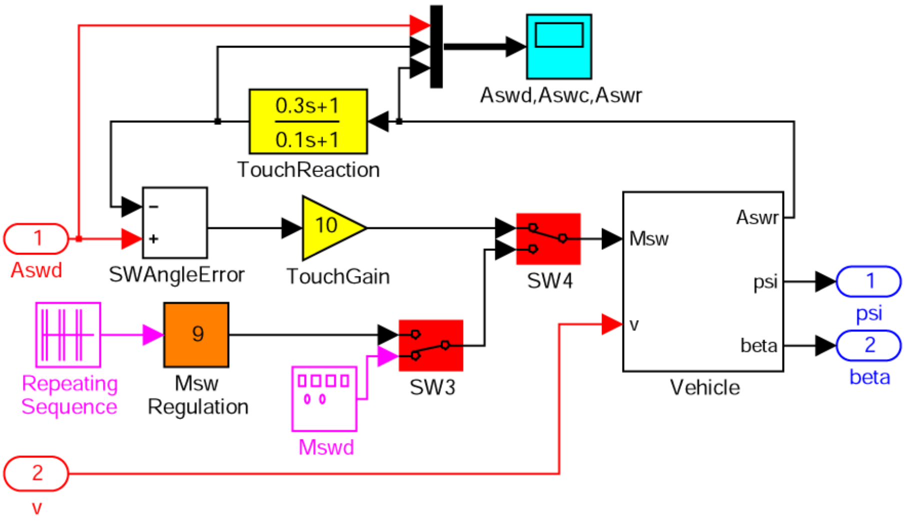

Fig. 2 Haptic (inner) feedback circuit of driver model

Due to the perturbations, the real steering wheel angle can differ for the desired one. The driver senses this by touch and tries, after a delay, to correct steering wheel position. The rapidity of his action depends on real angle's both change and rapidity of change. This is taking into account by the block **TouchReaction** (fig. 2), disposed in the feedback line. The emerging signal of this block is a corrected steering wheel angle, *Aswc*.

Other blocks in figure 2 are used to visualise data (**Aswd,Aswc,Aswr**) or, when switch **SW4** changes his position, to generate different time laws for the torque *Msw* applied to the steering wheel. This facility permits to compare reactions of same input actions for different vehicles or for the same vehicle but with changed functional characteristics.

The direct line of visual control consists (fig. 2) on a controller (block **PIDController**) that simulates the way the driver act when he see that vehicle has the tendency to deviate from the trajectory and on a function transforming deviation (metres) in steering wheel angle (radians) (block **VisualGain**). Both transformation gain and controller (with his proportional, integral and derivative parameters) can change their characteristics accordingly with vehicle responsiveness and driver experience and style.

Block **RealTrajectory** (fig. 1) computes the speed components in a fixed coordinate system

$$vx = v \cos(\psi+\beta)$$

$$vy = v \sin(\psi+\beta)$$

and then integrate them to obtain the absolute coordinates (x and y) of the vehicle's centre of gravity.

The deviation considered by the driver is not only the real deviation y of the vehicle. Because of the vehicle's heading angle $\psi+\beta$, the driver assumes an extra deviation observed by him at the distance (block **CorrDist**) where he intend to eliminate the current summed deviation. This summed deviation, delayed with the necessary time to process the information, subtract from the desired lateral distance y (block **TrajectoryError**). The result represents the error from the trajectory that will be the base for the estimation of a new desired steering wheel angle.

The anticipative component of the model realises by the block **DesiredTrajectory** (fig. 1). This can generate different desired trajectories, the desired lateral deviation being available at the output yd. The other output furnishes an anticipated desired lateral deviation, yda, as function of desired trajectory and the current distance travelled on x direction, generated by the block **RealTrajectory**:

$$yda = yd(x+da),$$

where da is the distance that the driver anticipates the manoeuvres necessary to be performed for a desired vehicle's trajectory. At high speeds, because this distance is travelled quicker, the driver disposes of shorter time to anticipate next necessary steering wheel handlings. In addition, the correction distance (block **CorrDist**) must be longer at high speeds, to give the driver the necessary time to react. As consequence, the trajectory error will be greater.

Switch **SW1** can be commuted between the two outputs, being obtained control ways corresponding with beginner or experienced driver. The other switch, **SW2**, can be used to break the feedback loop. In this case, the desired steering wheel angle *Aswd*, generated by the block **AngleSWdes** that simulates a driving robot, can be imposed.

EVALUATION OF HAPTIC CONTROL EFFECT

The next considerations try to put in evidence the effect of the driver action due to the un-commanded steering wheel rotation sensed by touch. For that, it was considered a gust of wind acting over the vehicle which must travel in straight-line. The aerodynamic force produced by the gust corresponds to a side wind velocity of about 30 km/h and has duration of 10 s. Figure 3 shows the time history of wind lateral force and of tyres side forces of both axles.

Sensing the un-commanded rotation of the steering wheel, the driver tends to compensate the deviation of the vehicle, acting with a torque having the evolution from figure 4. That produces a lateral acceleration with the magnitude from figure 5 and maintains a stable trajectory, the maximal deviation of about 80 cm producing in 50 m of travel, figure 6.

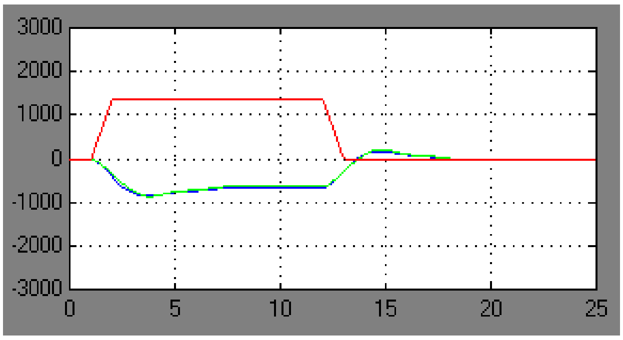

Fig. 3 Simulation of a wind gust effect at 72 km/h vehicle speed
red – aerodynamic force; green and blue – tyres side forces of front and rear axles

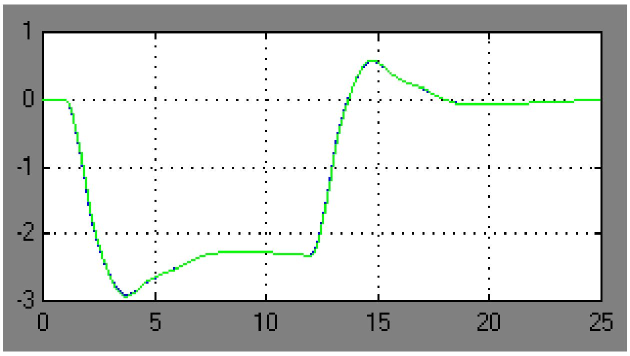

Fig. 4 Steering wheel moment compensating the gust effect

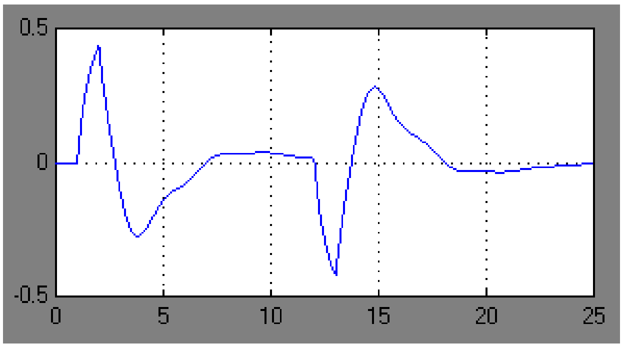

Fig. 5 Lateral acceleration produced by the gust and driver compensation

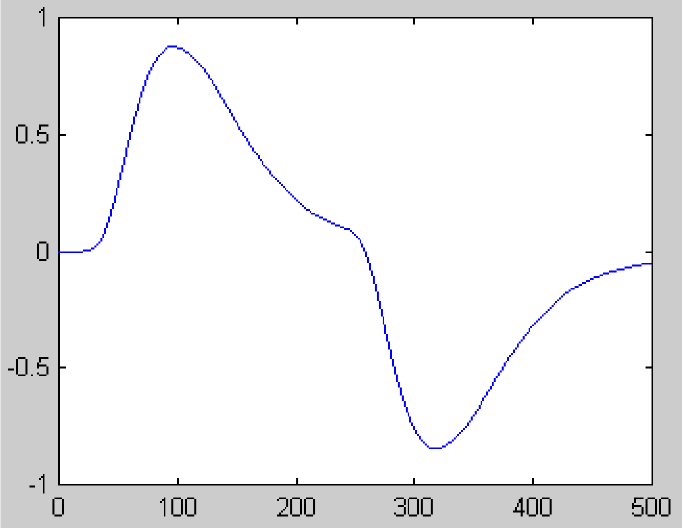

Fig. 6 Deviated trajectory during and after the gust

EVALUATION OF FULL DRIVER MODEL

One of the most used manoeuvres to appreciate the handling ability of a car is, accordingly with the norm ISO 3888, the double lane change, that corresponds to overtake or obstacle avoidance. The test permits to appreciate the handleability and roadability. The achievement on proving ground of such a test realises driving the vehicle with an imposed stabilised speed through a corridor with given dimensions, as the one presented at scale, with red lines, in figure 7. Here also shows successive car positions (plotted at equal time intervals), obtained by an anticipative drive but not well controlled. It observes that in this case the manoeuvre fails.

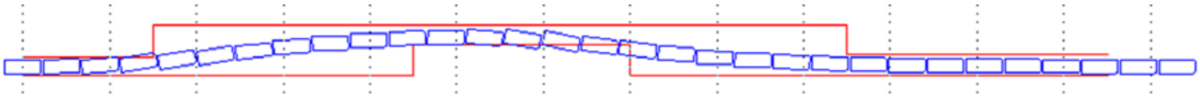

Fig. 7 Simulation of an overtaking manoeuvre

This situation can happened also in real tests and the consequence is that driver must accommodate with de vehicle. In the worst case, the driver (or maybe no driver) can pass the proof and the conclusion is that the vehicle's handling ability is not satisfactory.

Next five figures (8 to 12) plot results obtained during a simulated overtake at 72 km/h vehicle speed, this time the driver making the necessary corrections and passing the proof.

One parameter that permits a good appreciation of vehicle handling behaviour is the amplitude of steering wheel angle. Figure 8 shows time histories for the tree signals entering the block **Aswd,Aswc,Aswr** of figure 2, namely desired, corrected by touch sense and real steering wheel angles. Other suitable parameter to characterise the handling ability is the lateral acceleration, presented in figure 9.

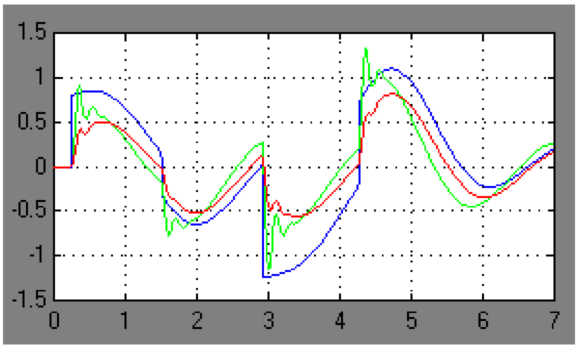

Fig. 8 Steering wheel angles vs. time in double line change manoeuvre at 72 km/h (blue – desired; green – corrected by touch sense; red – real)

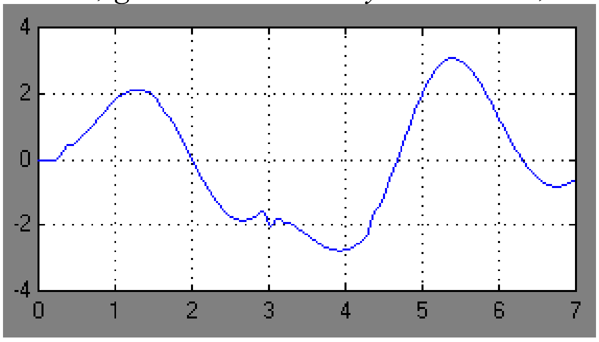

Fig. 9 Lateral acceleration vs. time in double line change manoeuvre at 72 km/h

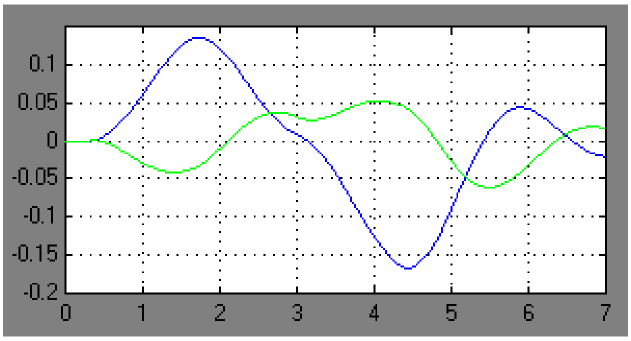

Fig. 10 Course angle (blue) and sideslip angle (green) vs. time in double line change

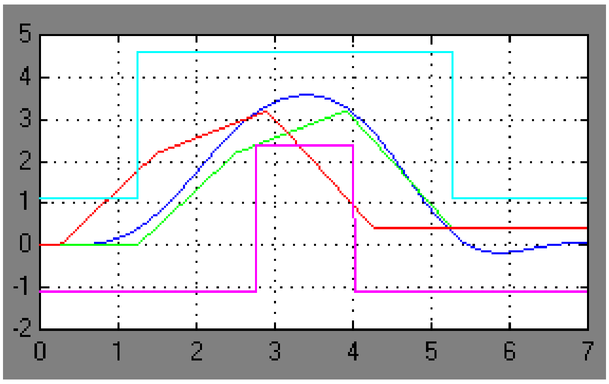

Fig. 11 Deviation vs. time in double line change manoeuvre at 72 km/h
cyan and violet – the limits of corridor; green – desired trajectory; red – anticipated desired trajectory (followed by driver); blue – real trajectory (permitting to pass the test)

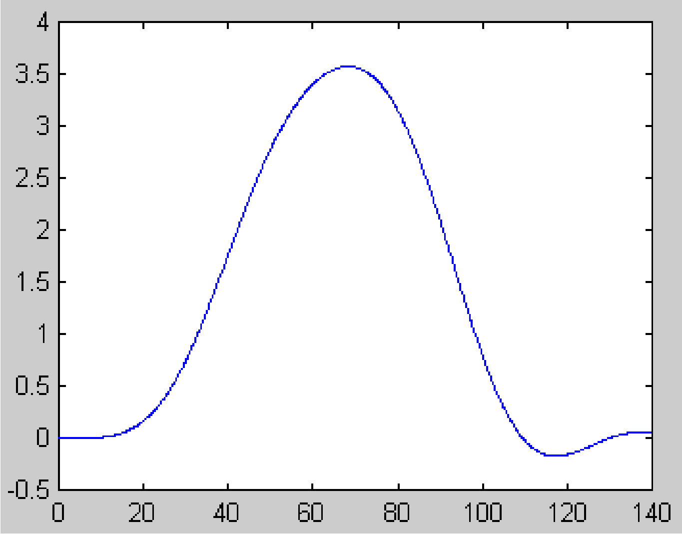

Fig. 12 Real trajectory in double line change manoeuvre at 72 km/h

Figure 10 presents course angle and sideslip angle (values in radians) as time function in the overtaking manoeuvre. As can be seen, at this speed the maximal sideslip angle is about 0.06 rad (3.4 deg), corresponding to a medium deviation and influencing the way the driver perceives the deviation from trajectory.

Figure 11 is a time representation of the way that the driver disposes to negotiate the overtaking proof. Transposed in time, the spatial corridor from figure 7 is delimited by the cyan and violet lines. Few failing tests “teach” the driver (and the authors of this article) that to obtain a good trajectory is necessary to act more slowly the steering wheel in the firs half of test than in the second. So, obtains the green line representing the first form of the desired trajectory. Then the driver "learns" to anticipate, translating this line with the time corresponding to 20 m of travel. So obtains the red line, that is the anticipating desired trajectory, and now the real trajectory (the blue curve) passes thru the corridor – manoeuvre succeeds. The corresponding real trajectory, transposed in space (meters of deviation vs. meters of travel), is plotted in figure 12.

At this time, it must be mentioned that the handling in this example can surely be optimised if the driver assures a smoother desired trajectory and the vehicle could pass the corridor with lower acceleration maxima.

COMPARISON SIMULATION - EXPERIMENT

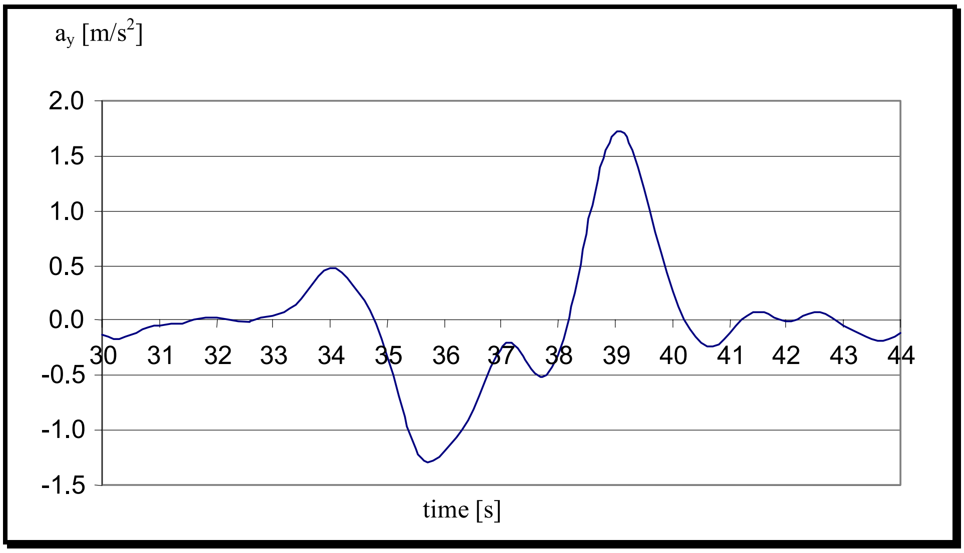

Fig. 13 Acquired data obtained during overtaking manoeuvre at 60 km/h

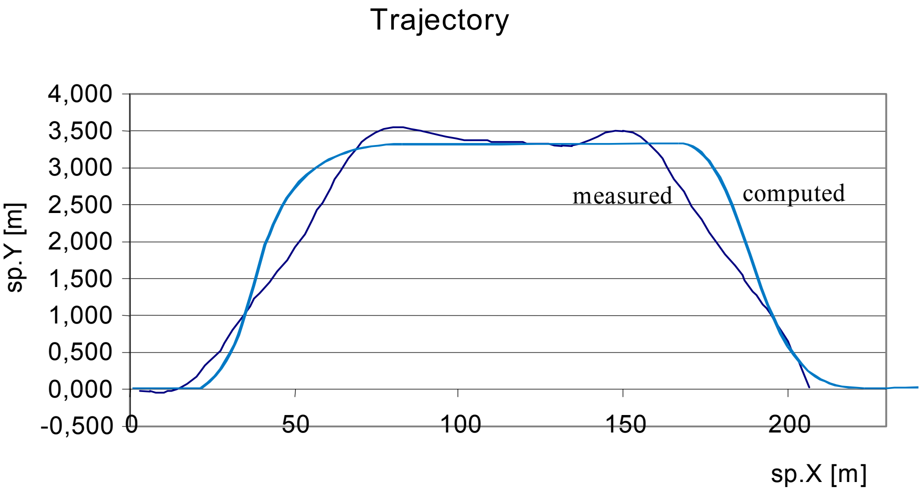

Fig. 14 Simulation-experiment comparison: computed and measured data, 50 km/h

To validate the model, a car was instrumented and many useful quantities were recorded with a mobile data acquisition system. Two kinds of tests were made in proving ground, slalom and double line change, and important number of time series was obtained (2).Different ride speeds were used: for slalom, 10 ÷ 50 km/h, and for overtaking, 10 ÷ 80 km/h.

Progressively increasing the tests speeds observes that maintaining the vehicle inside corridor became a difficult task for speeds exceeding 70 km/h.

Figure 13 present records obtained during a succeeding passing with 70 km/h thru the standardised corridor. Comparing this plot with figure 9, the shapes appear semblable and the peak values are proportional to the travel speed. Similarities can be also observed comparing the two plots from figure 14 that correspond to a succeeded passing thru the corridor at 50 km/h, the values being obtained by simulations and by processing of experimental data.

CONCLUSIONS

This article presented a computer model for the driver containing a subordinate feedback circuit and a governing visual feedback circuit. The model contains also an anticipative module. The implementation of this control system simulating driver actions was made using Matlab-Simulink software.

Theoretical response of vehicle-driver system was compared with on proving ground measured data, obtaining an encouraging correlation degree.

The model can be used in many ways, permitting to study different driving behaviours and styles, changing from inexperienced to a skilled driver.

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