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VEHICLE-DRIVER BEHAVIOURAL-RESPONSES DEFINED BY RADIO-NAVIGATION SYSTEM GPS

ABSTRACT

From the very beginning of its usage the navigation system GPS has been applied in studying the cases of the car following behaviour of two-vehicle platoons. The navigation receiver is used for vehicle position and speed data collections. The measurement accuracy is to be improved by the real-time dGPS correction-data or by additional data post-processing. For additional measurement of the vehicle-to-vehicle separation, both vehicles should be equipped with a GPS receiver. The vehicle-to-vehicle separation is calculated later on, during the data post-processing.

This paper describes the choice of the experimental setup, on the basis of the radio-navigation system GPS, which may be used for recording the data on location, speed and time. The presented measurement results have been attained in two steps: first, the data were collected, through the process of tracking of two-vehicle platoons in real life traffic-flow, and then processed. The selected mathematical model is based on the PID controller in the closed-loop control system. It enables evaluation of the measurement results and assessment of the behavioural elements of each driver.

KEY WORDS

traffic flow micro-model, navigation system GPS, PID controller, driver behavioural-responses

1. INTRODUCTION

The Traffic Flow Theory is the first and the basic knowledge on traffic. It tries to explain events, connected with the vehicle drive and the vehicle interaction with other participants in the traffic. Due to traffic-flow research, it has been possible to determine road characteristics such as capacity of the roadway and its ability to convey the different type of traffic. Knowing these road characteristics is the most important factor in successful and economical exploitation of the vehicle [1].

The Traffic Flow Theory describes and explains the basic traffic flow simulation models and other re events such as: how the traffic stream comes to existence, measuring and supervision of the traffic stream, and potential traffic accidents. The usage of these different simulation models has been researched for the purpose of traffic improvement and implementation of the ITS (Intelligent Transport Systems).

The Traffic flow Theory deals with the transport system at the macroscopic and microscopic levels. At the macroscopic level, the system is dealt with as fluid, which flows through the pipe. While a vehicle itself, and its interaction with other participants in the traffic, is dealt with at the microscopic level.

2. DESIGNING AN EXPERIMENTAL SETUP

In the past, the most precise measurements of the vehicle-to-vehicle separation were performed on the basis of tow-wire-length measurement. The wire was strained between two cars and a winding-up drum was used to control its tension. Such measurements could be performed only on the roads secured with barriers, for testing purposes [2].

Today, we use the radar [3] for precise laboratory measurements of the vehicle-to-vehicle distance. The

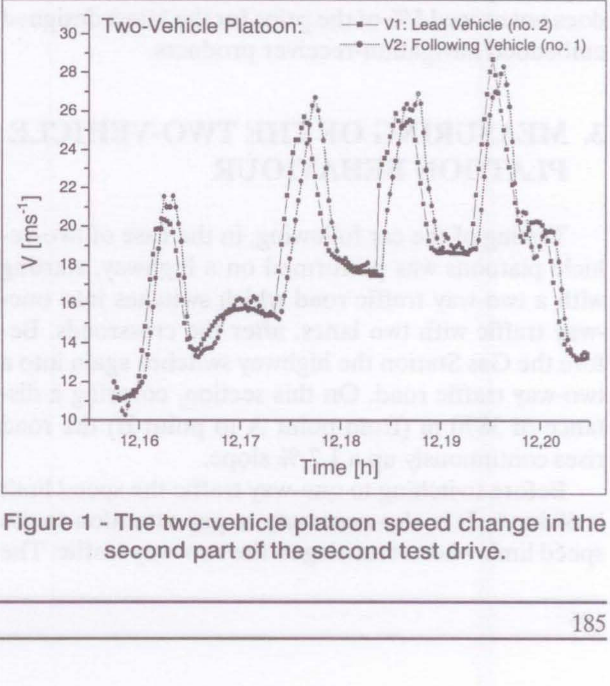

Figure 1 - The two-vehicle platoon speed change in the second part of the second test drive.

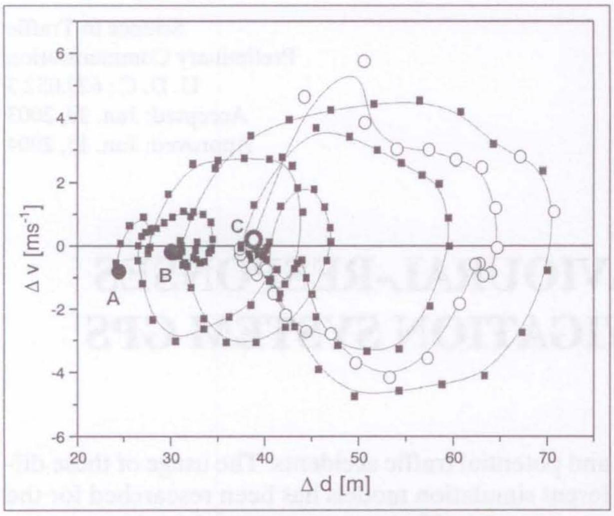

Figure 2 - The two-vehicle-platoon relative speed referring to their vehicle-to-vehicle separation

radar measurement is extended by the precise gyroscope. This Dead Reckoning Instrument obtains a vast range of vehicle-movement data and supplements the related system for positioning the vehicle.

For measuring the position, speed and vehicle-to-vehicle separation two AllStar Type GPS receivers, CMC Electronics Canada products, have been purchased. The basic forms (Option 1: 1 Hz phase measurement @ 19200 Baud) and supplemented forms for all differential corrections (Option 12: WAAS/EGNOS-DGPS). The only difference between them is their software. Both receivers are equipped with the outside antenna, which can amplify the signals up to 26dB. The navigation embedded OEM receiver AllStar, has 12 independent input channels and sends the navigation data to the master computer at 1Hz frequency. It can indicate the position with an accuracy of less than 1m, if it gets the correction signal from the GPS, otherwise its indication is of less than 16m accuracy. The price for the basic-version of such a receiver does not exceed 5% of the price for the latest designed embedded navigation-receiver products.

3. MEASURING OF THE TWO-VEHICLE PLATOON BEHAVIOUR

Testing of the car following, in the case of two-vehicle platoons was performed on a highway, starting with a two-way traffic road which switches into one-way traffic with two lanes, after the crossroads. Before the Gas Station the highway switches again into a two-way traffic road. On this section, covering a distance of 3870 m (from point A to point B) the road rises continuously up a 1.7 % slope.

Before switching to one-way traffic the speed limit is 60 km/h. It is also necessary to pay attention to the speed limit when returning to the two-way traffic. The direction of driving can be changed by crossing the bridge at the crossroads on the start of the test-road and by turning left at the second change to two-way traffic. The selected section between points A and B provides the highest possible security for test-measurements performance in the real traffic stream. Other participants in the traffic are able to pass the vehicles without disturbance, using the left overtaking lane.

For this test two common passenger cars were used. Every test encompassed two drives. For the second drive the following and the lead vehicle changed their positions. For example, in the first test measurement the driver W drove the lead vehicle 1. In the second test measurement the mentioned vehicle was the following vehicle, and the lead vehicle was vehicle 2 with driver Z. The drivers W and Z for the two tested vehicles were selected among two opposite groups of drivers. Driver W was a younger person and an automobile fan. Driver Z was an older average driver, whose level of response was intentionally slowed down compared to driver W, as he could brake only with the hand brake. Each test started and finished on the parking lot at the end of the one-way road. That was also the start and finish of the laptop computer recording of each test.

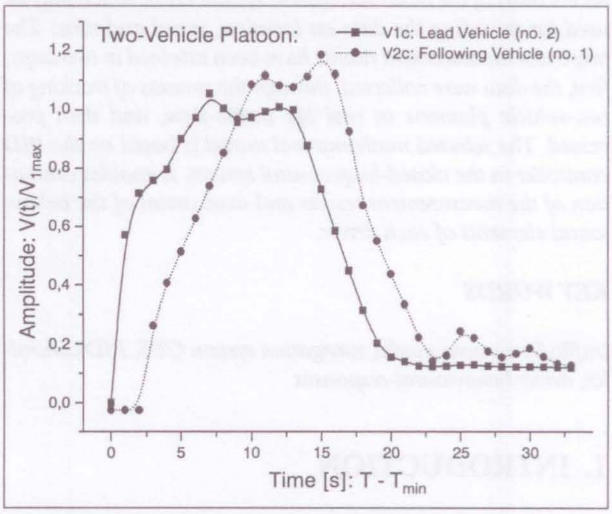

Figure 3 - Shape of the third standardized disturbance in the second drive, during the second test measurement

4. PROCESSING AND EVALUATION OF THE MEASUREMENT RESULTS

Successfulness of each measurement was evaluated later on, using a common diagram for the test vehicle speed change in time v = f (t), which was done according to the collected data on each vehicle, which took part in the two-vehicle platoon (Figure 1).

Then, the starting relative speed diagrams were designed referring to vehicle-to-vehicle separation

(Figure 2). The presented diagram is a pattern of two-vehicle-platoon drive. It was recorded during the test measurement performed on the A – B section. The beginning of the third disturbance C is additionally drawn in this diagram. During further driving the relative speed increased first and after that the relative vehicle-to-vehicle separation as well. The relative speed increase calmed down and then began to decrease. At the end of this transitional occurrence the curve calmed down in the vicinity of the point C and finished its almost circular motion.

To make the comparison of the measurement results with the simulation-model results, we standardized the transitional occurrences. The transitional occurrence was observed from the beginning of the disturbance in the traffic flow to its expiration or the beginning of the next transitional occurrence. An average value between the peak values for each particular disturbance induced in the system was taken as the starting value for the amplitude. The sample of the third disturbance standardization (Figure 1) is also used for additional presentation of the two-vehicle platoon in the traffic-flow simulation-model results (Figure 3).

5. DYNAMIC MODEL OF VEHICLE-TO-VEHICLE SEPARATION

When the disturbance was introduced, the driver estimated the acceleration of the lead vehicle. Equation (1.1) is the first approximation of the following-vehicle response.

$$\ddot{x}_{lead}(t+T)=\lambda[\dot{x}_{following}(t)-\dot{x}_{lead}(t)] \qquad (1.1)$$

The first approximate equation of the two-vehicle platoon dynamic behaviour in the traffic flow is a very simple description of controlling vehicle in the traffic flow, which is a very complex process.

On the basis of the standard control theory, the linear model of the car following was designed and its block diagram is presented in Figure 4. In this diagram the driver is presented with two basic elements: the delay element and the proportional element with amplification. For more accurate presentation it is necessary to design a set of equations which are able to describe the driver behaviour more precisely. The psychological & physiological factors and the interaction with other vehicles in the traffic flow also have to be included. Besides the lead vehicle that influenced the following-vehicle-driver decisions and his response speed, there were also a vehicle behind him, traffic regulation and the road-safety that influenced him as well.

The two-vehicle-platoon straight-movement can be simulated with the PID [2,4] controller characteristics. This research objective was to reach constant separation D between the lead vehicle n+1 and the following vehicle n, with error e(n+1), by tracing the lead vehicle n+1 (1.2).

$$e(n+1)=d(n+1)-D=x(n)-x(n+1)-D \qquad (1.2)$$

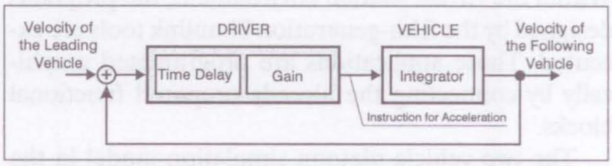

Figure 4 - Block diagram of the two-vehicle-platoon behaviour linear model

The vehicle-to-vehicle separation d(i) is measured by the system for defining the single vehicle position. The successfulness of the tracing can be presented by the third order differential equation (1.3).

$$\ddot{x}(n+1)=c_p e(n+1)+c_v\dot{e}(n+1)+c_a\ddot{e}(n+1) \qquad (1.3)$$

The transfer function H(s) for regulation with the feedback closed-loop controller (1.4) describes, in the Laplacean space, the deviation from setup vehicle-to-vehicle separation D for two-vehicle platoon in the traffic flow.

$$H(s)=\frac{e(n+1)(s)}{e(n)(s)}=\frac{c_a s^2+c_v s+c_p}{s^3+c_a s^2+c_v s+c_p} \qquad (1.4)$$

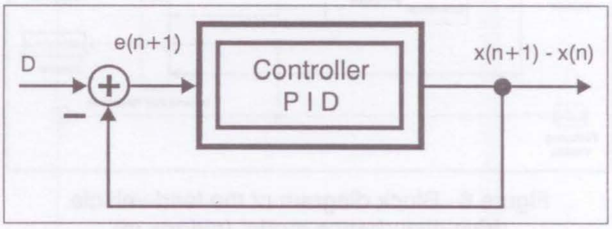

Figure 5 - Block diagram of the PID controller in the closed-loop control system

The PID-controller parameters in the feedback closed-loop control-system (Figure 5), for position c_p, speed c_v and acceleration c_a, should be selected in such a manner as to assure stable regulation. Therefore, the system transfer-function H(s) has to satisfy the condition $|H(j\omega)| < 1$ for each value of ω. To prevent the potential model oscillations from exceeding the highest values allowed, the system response has to be $h(t) > 0$ for each $t > 0$.

6. DYNAMIC-MODEL DESIGN BY SIMULINK SOFTWARE TOOL

To determine the properties of the dynamic simulation model for two-vehicle platoon in traffic flow, we have used the Matlab tool Ver. 4.2c1/1994 [5] and corresponding Simulink tool Ver. 1.3c [6], which are both USA MathWorks products.

Matlab tools are designed for applications written in the programming language of the third generation. At the same time it is a virtual computer which runs the applications using its own operation system. Within the virtual Matlab environment, the programs designed by the fifth-generation Simulink tools are executed. These applications are programmed graphically by connecting the already prepared functional blocks.

The two-vehicle platoon simulation-model in the program pidgps.m, has been designed in Simulink (Figure 6) as PID controller, included in feedback control-loop (Figure 7) [7]. The program pidgps.m envisaged that the correct tuning of PID parameters should be set up manually. The duration of a single transitional occurrence is 32 seconds with the longest possible simulation step ≤ 0.5 second. The program pidgps.m acquires the information on disturbances which occurred or on the lead-vehicle way of driving, from the program kvadrip.m, and then sends out the simulation results back to the kvadrip.m. The program kvadrip.m runs in the Matlab operation environment.

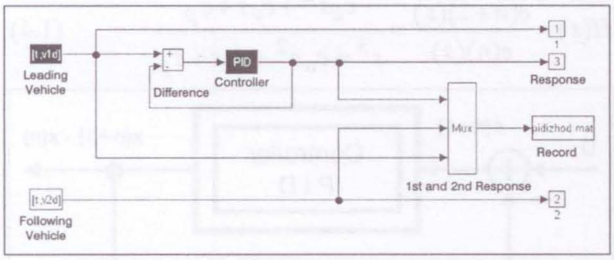

Figure 6 - Block diagram of the lead-vehicle drive-disturbance model (pidgps.m)

The program kvadrip.m acquires data from the files*.mat, which contains the measured and the standardized values for single vehicle and disturbance occurrence. It also sends out the data on lead-vehicle speed to the program pidgps.m, from which the data on simulation results are acquired. The data on the simulation results are to be displayed in the Matlab instruction window, and from them the program calculates the sum of the squared differences (between the measured and the simulation-result values) to get the variation of the following-vehicle speed. As the criterion for successful simulation we have assumed the minimum sum of the squared deviation values $\Sigma\Delta^2$ (Figure 8).

On the basis of prior simulations it was defined that the most proper area for simulation is between the values 0.0 and 1.0. It is worth for defining the integral amplification factor K_p, or road factor K_p and the differential amplification factor or acceleration factor K_d of the PID controller. In this area the regulation was stable and the sum of the squared differences reached its minimum. The most appropriate step was 0.1. The prior simulations have also found that the proportional amplification or speed factor = 0.001 is the same for all transitional occurrences that have been dealt with.

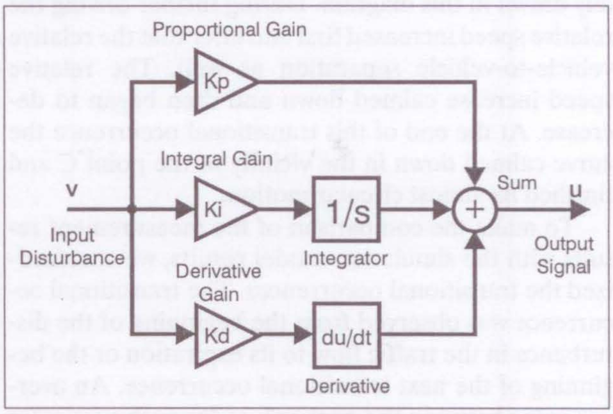

Figure 7 - Block diagram of the linear state PID controller

The tables (Table 1 and Table 2) present the results of the measurements and the test simulations of the driver W and Z behaviour. By means of the PID controller included in the feedback closed-loop control system, the factors Ki and Kd for the first and the second driver have been defined. From the known characteristics of the PID controller, the level of response and the car following behaviour for individual driver in the real traffic can be defined. The results have shown that the response of the driver W is quicker than the response of the driver Z, because his factor K_i is smaller. His factor K_d is also smaller and it shows that he is also better in following the variations in the traffic stream.

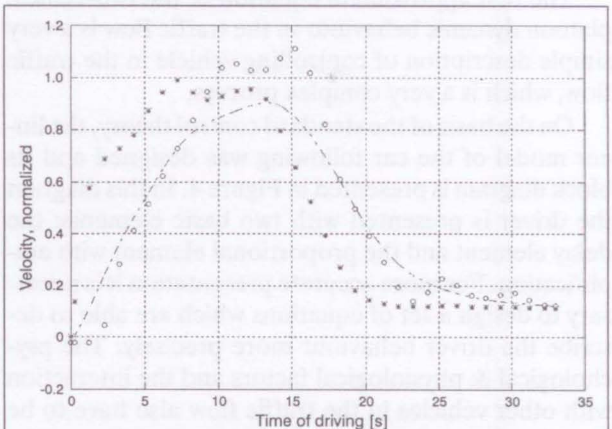

Figure 8 - Simulation result (-. -. -.) for the third disturbance

1. The results of this research have shown that the set up two-vehicle platoon simulation model, with the PID controller in the feedback close-loop control system can be used for two basic purposes.

Table 1 - Test 1 – driver W of the following vehicle

Transitional occurrence	Disturbance measuring				PID controller			Simulation
	N [n]	V(1) [ms^{-1}]	Vmax [ms^{-1}]	V(N) [ms^{-1}]	Kp	Ki	Kd	$\Sigma\Delta^2$
Drive 1								
a	46	16.663	20.236	23.808	0.001	0.30	0.00	0.0210
b	44	18.406	22.260	17.163	0.001	0.40	0.40	0.0284
c	61	17.834	21.382	0.0190	0.001	0.30	0.00	0.0312
Drive 2								
d	51	12.555	24.611	19.223	0.001	0.30	0.00	0.0049
e	43	18.614	23.047	18.885	0.001	0.30	0.30	0.0326
f	59	19.206	23.421	4.691	0.001	0.30	0.00	0.0349
Average	51	17.213	22.493	13.965	0.001	**0.32**	**0.12**	0.0255

Table 2 - Test 2 – driver Z of the following vehicle

Transitional occurrence	Disturbance measuring				PID controller			Simulation
	N [n]	V(1) [ms^{-1}]	Vmax [ms^{-1}]	V(N) [ms^{-1}]	Kp	Ki	Kd	$\Sigma\Delta^2$
Drive 1								
a	61	15,389	23,462	19,032	0,001	0,40	0,30	0,0089
b	38	19,032	25,117	15,687	0,001	0,50	0,30	0,0186
c	56	15,687	23,044	11,068	0,001	0,50	0,90	0,0082
Drive 2								
d	50	11,457	20,339	15,460	0,001	0,60	0,10	0,0057
e	39	15,406	25,707	17,682	0,001	0,30	0,20	0,0100
f	34	15,406	25,707	17,682	0,001	0,30	0,00	0,0110
g	34	18,601	28,684	15,143	0,001	0,50	0,70	0,0076
Average	45	15,854	24,580	15,965	0.001	**0,44**	**0,36**	0,0100

2. The verification of the tracing two-vehicle platoon measurement results for different drivers in real life traffic flow, where the results for the same measurements are verified for different position-measurement frequencies and different disturbances in the traffic flow.
3. The behaviour of different drivers is found by means of dynamic measurements in the real life traffic flow, and their levels of response are compared.

7. FURTHER DISCLOSURE OF TRAFFIC FLOW RULES

Researches of the traffic flow, at the macroscopic level, are performed also in order to obtain the knowledge on different rules of the traffic flow which is composed of vehicles with different behavioural elements [8]. Such simulation models are closer to real life traffic flow behaviour. The highway entrances and exits are examined closely, as the increase in traffic flow might cause a traffic jam, and also the fast speed change on the entry slip roads is always risky.

The latest two-vehicle platoon behaviour researches objective is to increase the safety and reliability of vehicle travelling and to unburden the driver by means of automatic car control [3]. For fulfilling such objectives the important thing is the combining of the navigation-receiver for vehicle positioning and the computer for marking such position on the electronic map and processing of the collected data. The system acquires and sends out the data most often by personal mobile telephone. The simulation model of the two-vehicle platoon is supplemented by more precise measuring results, the vehicle behaviour [10, 11] measurements are simplified, and the embedded safety-signalling system reliability is examined.

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POVZETEK

LASTNOSTI VOZNIKA OSEBNEGA VOZILA DOLOČENE S POMOČJO RADIO-NAVIGACIJSKEGA SISTEMA GPS

Od samega začetka postavitve navigacijskega satelitskega sistema GPS se je za meritve voznih lastnosti dvojic vozil, ki vozita eden za drugim, uporabljal tudi ta navigacijski sistem. Navigacijski sprejemnik služi kot merilec pozicije in hitrosti vozila. Točnost njegove meritve se izboljšuje s pomočjo korekcijskih podatkov dGPS v realnem času ali pa s kasnejšim preračunavanjem podatkov (postprocesiranje). V kolikor se meri tudi medsebojna razdalja, se s sprejemnikom GPS opremita obe vozili. Medsebojna razdalja se izračuna ob kasnejši obdelavi podatkov.

V prispevku je opisana izbira merilnega sistema za merjenje pozicije, hitrosti in časa, ki sloni na radionavigacijskem sistemu GPS. Predstavljena je meritev sledenja dvojice vozil v realnem prometnem toku in načinu obdelave izmerjenih rezultatov. Izbrani matematični model izhaja iz modela regulatorja PID v zaključeni regulacijski zanki. Omogoča ovrednotenje merilnih rezultatov in ugotavljanja vozniških sposobnosti posameznega voznika.

KLJUČNE BESEDE

mikro-model prometnega toka, navigacijski sistem GPS, regulator PID, lastnosti voznika

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