CTU0612216

Measurements and analysis of data measured from real car driving used for development of research driving simulators

Author: Ing. Petr Bouchner, Coauthors: Ing. Stanislav Novotný, Ing. Roman Piekník

(Dissertation Thesis: Driving Simulators for HMI Research)

Supervisor: Prof. Ing. Mirko Novák, DrSc.

Czech Technical University in Prague, Faculty of Transportation Sciences
Department of Control and Telematics
Konviktská 20, Prague 1, 110 00

Abstract – The Common Laboratory of Systems Reliability of Faculty of Transportation Sciences CTU and Academy of Sciences of Czech Republic (LSR) works many years on research in the field of reliability of operator-machine interaction. Driving simulators, which are continuously developed by the DSRG (Driving simulation Research Group) are successfully used for experiments dealing with investigation in driver's behavior under normal and marginal conditions, and influence of in-car devices on driving safety and comfort.

Aim of the work - Although the experiments were originally focused mainly to obtain data for development of driving simulators, they opened us additional ways of usability. The aim of this work is now divided into three parts:

1. Investigate in possibilities of measurements of Driver-Car interaction in real cars in real traffic, first approach for future development of so called "instrumented vehicle".
2. Obtain data from different testing scenarios which would be used for development and tuning of physical model and motion cuing modules of our driving simulators.
3. Validation of contemporary features of our simulators.

Introduction

The driving simulators are considered either as research tools or as a basis for a driver's training. Those which we have developed and used in the LSR are used for both of these purposes. Since no simulation device could ever offer a human subject a complete set of cues like they appear in reality, it is necessary to be sure that the stimuli impacting on the human are sufficiently convincing as for the needs of an actual experiment. From that point the necessary condition is the validation for an each experiment or a branch of experiments with the very similar perception cues. To be precise we need to ensure that the proband, who are driving the simulator, will behave in at least a very similar manner like in the case of driving a real car. Even though it is not possible (or sometimes not desirable) to copy simply the responses and behavior of a real car, those measurements are necessary preconditions for quality and valid simulation. From the point of view of usability of measure data, we divide them into two groups: the data used for simulator system design and the data used for experiments validation.

Quality of simulation of any human operated system relies on an ability of simulators to cheat the human senses in such a way that the human driver can accept the simulation to be reality. For this reason it is necessary to have deep knowledge of common behavior of the simulated system. As it was mentioned before, stimulating all the aspects in their full range is almost an impossible task and one should concentrate on those most impressive aspects.

Data Collection

The acquisition of the performance data from car driving used to be a very complex and expensive task. Of course when precise data are necessary such measurements are also complicated even today. Fortunately the modern cars which are equipped with electronic advanced driving assistance devices utilize many different electronic sensors of physical quantities. Data from those sensors are digitalized and transferred to the computational and controlling units via digital buses. It is possible to take advantage from this communication and scan and store the data without any serious intervention into the car itself and without any need of any external measuring devices.

Trajectory

The path of the vehicle is obtained from GPS signal in 2D coordinates. Unfortunately, correct usage of GPS signal for trajectory is not always enough frequent and the correctness of the immediate localization when moving is also problematic. The range is at about 3-8m and from that reason it serves for car position identification. Average localization frequency is about 3-4 seconds, the points for example in highway segments are in average around 100m from each other. Therefore it was necessary to interpolate within the measured points. A spline interpolation seems to be suitable.

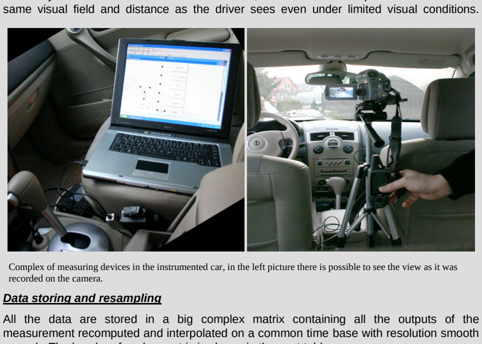
Car performance data

All the necessary data were collected via car CAN-bus protocol and CAN diagnostics. They give evidence of car's response to driver's behavior. These were actual values of:

1. Car velocity in km/h (and proportional speed of rotation of each of car wheels)Vertical - in g and longitudal - in m.s-2 - accelerations
2. Spinning velocity of the car in degrees/s
3. Revolutions of the engine, the gear
4. Position of throttle pedal in percentage, depression of brake pedal (here only on/off position)
5. Position of steering wheel in degrees and its velocity in degrees/s
6. Torque, which the driver forces on the steering wheel and force developed by power steering, all in N/m

Camera recording

Video record from the ride was recorded using a common digital camera with a high sensitivity and with a wide FOV had to be used, so that it would be possible to record the same visual field and distance as the driver sees even under limited visual conditions.



Complex of measuring devices in the instrumented car, in the left picture there is possible to see the view as it was recorded on the camera.

Data storing and resampling

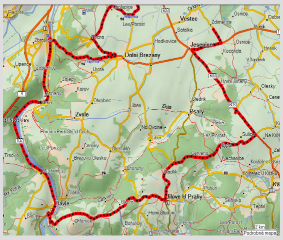
All the data are stored in a big complex matrix containing all the outputs of the measurement recomputed and interpolated on a common time base with resolution smooth enough. The header of such a matrix is shown in the next table.

Revolutions						Velocity		Accelaration		Stearing vheel				Controls		
TIME	FR	FL	RR	RL	MOT.	VEH.	YAW	LINEAR	LATERAL	ANGLE	TURNS	TORQUE	POW. ST.	GAS	BREAK	GEAR
ms	Revolutions per minute					km/h	°/s	m/s²	g	°	°/s	N/m	N/m	%	0/1	

Structure of the matrix of worked out CAN data recorded during the experiments

Testing circuits

From the next picture it is possible to see one of the testing circuits on which the measurements were performed. It consists of segments of various complexity and driving demands. There is a part in kind and almost straight road with large view in distant as well as very demanding parts of rural environment full of curves and elevation changes. A city road driving is also included in this circuit. Moreover we included a slick (icy) parking lot for testing of driver-assistance systems (ABS, ESP).



Testing circuit 1. – Rural and city environment near Prague

Basic segment types:

1. Highway
2. Rural environment
3. Town environment
4. Starting
5. Stopping
6. Slalom
7. Overtaking

Main testing circuits:

1. Prague and suburbs
2. Highway track D1
3. Highway track D8
4. Rural demanding track
5. Highway track Prague-Regentsburg (with speeds > 130 km/h)
6. Parking lot

Tool for data segmentation

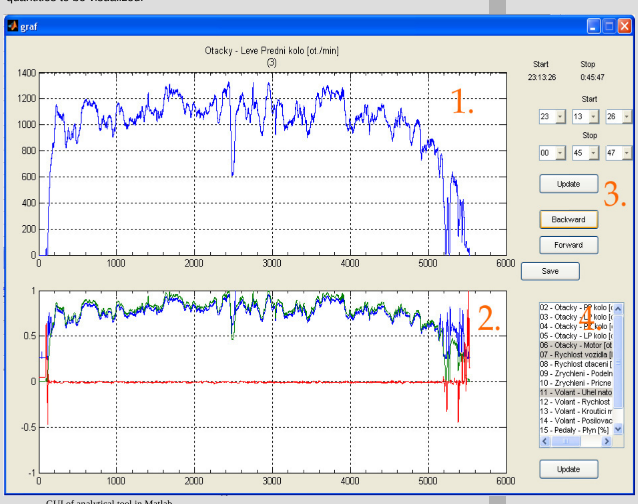
To have enough knowledge about the driver's behavior on various types of roads in diverse environments under different driving conditions it is necessary to create a tool witch allows easy and tabular view on the complex data set. We chose the Matlab environment with visual toolbox for interactive work with data. The workspace is composed of four main functional blocks:

1. A single quantity graphical visualization window which shows actual development of selected measure in its real values in the appropriate commonly used units and with progressively changeable scale and range. One can move from quantity to quantity easily by pushing forward and back buttons.

2. Multiple quantities graphical visualization window which can allow direct comparison of different quantities measured at the same time base. This window shows the values of chosen quantities in its normative expression because of the fact that some of the quantities are of very different scale and otherwise one would not be able to see them in the same window. The normalization process is done prior to visualization from the whole segment of measured data to avoid the inadequate scaling.

3. Controlling buttons which allow us to choose wanted segment of the data matrix based either on our preference or automatic generated segmentation from GPS tracking system. The selected segments can be either visualized only and/or saved into the separate matrix which serves for further analyses.

4. Data selection window. Within this list one can easily select which of the quantities are to be shown in the comparison graphical output. It is possible to select arbitrary amount of quantities to be visualized.



GUI of analytical tool in Matlab

Data segments statistics

The following complex table presents results of basic statistical analysis. Only selected variables and interesting and clearly definable parts of the tested circuits are shown.

Segment	statistics	RPM	Speed [km/h]	Long. Acc [ms-2]	Lat. Acc [g]	steerig wheel angle [o]	Steering whee torgue [N/m]	pws enforsing togque[N/m]	throtle [%]
Rural circuit complete	mean	1842,2	57,7	0	0	-5,3	0	0	17,2
	std	590,55	23,31	0,9841	0,0824	38,1868	1,4443	2,2911	23,4557
	min	702	0	-5,9127	-0,509	-317,6989	-4,3696	-12,6	0
	max	4561	116	2,7	0,5	425,2	4,7	12,7	0,1137
	median	1866	59,7	0	0	-3,8	0	0	10,6
Highway night foggy	mean	2406,7	113,2	0	0	-3	0,2	0,1	25,4
	std	213	10,03	0,2156	0,0266	1,993	1,085	0,4856	6,996
	min	1812	85,4	-1,8	-0,1	-10,8	-2,8	-3,6	0
	max	2891	136	2,7	0,1	4,6	2,9	3,9	66,3
	median	2419	113,8	0	0	-3,2	0,1	0	25,5
Higway - streight segment	mean	2433	114,5	0	0	-3,3	0	0	25,3
	std	218,5	10,29	0,2399	0,0262	1,7561	1,0437	0,4432	8,7209
	min	1985	93,5	-3,1	-0,2	-8,9	-2,5	-2,9	0
	max	2878	135,5	2,3	0,1	4,1	2,9	4,5	55,3
	median	2382	112	0	0	-3,4	0	0	25,5
Rural circuit forest uphill	mean	1934	49	0	0	-20,8	0,1	-0,1	23,7
	std	846,42	26,65	0,999	0,1074	42,4049	1,5699	2,5863	32,0168
	min	781	0	-4,3	-0,5	-23,6	-3,6	-12,6	0
	max	4561	97	2,7	0,4	73,1	4,3	11	113,9
	median	1862	53,7	0	0	0	0,3	0	13,5
Rural circuit steight in forest	mean	1867	58	-0,1	0	6,3	0,4	0,4	18,3
	std	497	23,45	0,86	0,07	106,7	1,38	3,34	19,2
	min	748	0	-3,75	-0,403	-555	-3,9	-12,6	0
	max	4572	100	2,7	0,4	562	8,3	12,7	113
	median	1961	53	-0,1	0	-0,32	0,3	0	16,8

Statistics of selected variables form different segments of testing circuits

Usability of results from the measurements

Perceptions of motion (i.e. moving in all 3 main axes, yawing and rolling, vibration coming from various sources and directions) and perceptions of an arbitrary acceleration play a very important role in the process of car controlling.

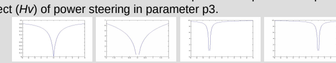
Haptic feedback on the steering wheel

Steering is actually the most direct way of how the driver feels reactions of the car to his/her control actions. The correct behavior of a feedback of the steering wheel is essential for correct path keeping. The feedback force does not need to rely on predefined curves but it can take advantage of detail computation inside of the physical engine. It can take into account also the actual velocity and rolling forces the front wheels.

A torque generated by the electronically driven servo motor can be expressed basically by an equation of non-linear spring. We also need to take into account a progressiveness of power steering which depends on the instant car speed. Since the real time controlling processors could not compute any complex functions, our first approach to the response function should be simple:

$$\tau = \frac{-1}{abs(\omega + p1(\omega)) + p2(v)} + p3(Hv)$$

This equation of the responding torque generated on the steering wheel, takes into account an actual angle (ω) of the steering wheel in parameter p1, an actual velocity (v) of the car - approximating physical behavior of the front wheels - in parameter p2 and stepwise progressive enforcing effect (Hv) of power steering in parameter p3.

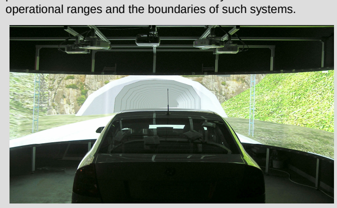


Parametric curves depicting the simulated steering wheel response

Conclusion

The analyses of measured data can serve for various purposes within the process of development of research driving simulators. First of all they can be used for tuning quality of car physical model, second for algorithms controlling simulator in-car dynamics (i.e. motion cueing and haptic and vibration feedback of various parts of the car-cockpit which a driver gets in touch with). Till now the first approach to steering wheel feedback being developed in our laboratory was done.

Main usage of the data measured in this part of the experiment serve for deep understanding of car to drive responses in different segments (types) of roads under different conditions. Such a knowledge significantly helps to design accurate motion platform controlling algorithms providing the driver with realistic and appropriate feelings from the simulated driving. It is possible to derive from the statistical analyses of those data the operational ranges and the boundaries of such systems.



One of our four simulators, which use in its physical model and feedback on the steering wheel based on the measured and analyzed data.