CONTROL AND ANALYSIS OF SIMULATOR AND BIOLOGICAL DATA FROM CAR SIMULATORS

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Abstract
Due to the fact that driving vehicles can be complicated or impracticable, a computer simulator is usually used for training and professional studies. The advantage of this approach is high safety, repeatability, easier feasibility and, of course, lower price. In this work we describe the extension of the car simulator developed by the Faculty of Transport CTU in Prague with specific scenarios for evaluating the cognitive abilities of probands, software for their management and evaluation of data from simulator software and other measured physiological variables such as ECG and arm movement. From the data it is then possible to evaluate the mental and physical condition of the proband and the progress of training. Preliminary results suggest the possibility of using Poincaré analysis for the purpose of assessing cognitive load during potential collision situations. It uses distance assessment from other objects involved in traffic situations.

Keywords
car simulator, vehicle driving, driving data, biological signals

Introduction

Car simulators are used to evaluate various types of biological signals, including electrocardiogram (ECG) [1, 2], electroencephalogram (EEG) [1, 2], electrooculography (EOG) [2], and electrodermal activity (EDA) [1] during driving. In addition, simulator data such as steering wheel movement (SWM) is used to assess drowsiness, since drowsiness reduces the number of steering wheel micro-corrections and which also affects the standard deviation of lane position (SDLP) [3]. Reaction times for specific difficulties e.g. lower limbs after total knee arthroplasty are also evaluated [4].

This paper is a follow-up to our previous publication that dealt with the design of a car simulator for the selection and screening of patients after brain injury [5].

The clinical requirement of the physiotherapists was the possibility of easy selection of scenarios with different difficulty levels and subsequent automatic evaluation including the final score for the proband. The final score is important to increase motivation in the rehabilitation process [6]. For these needs, an application with a graphical user interface (GUI) was developed in a Matlab environment. This work brings enhancements mainly in the design of new scenarios, processing and evaluation of electrocardiogram and arm movements recordings and simulator data.

Methods and materials

Hardware

Car simulator, developed by the Faculty of Transport CTU in Prague and described in detail in [5], fulfilling the conditions for category 3 car simulator according to Act No. 247/2000 of the Czech Republic, was used for the measurements. The measured biosignals included ECG recorded by Wireless 12-lead ECG EDAN SE-1515 DX12 PC with a sampling frequency of 500 Hz and stored in DICOM format with timestamps [5]. Ag/AgCl electrodes were connected, due to limb movement during the driving simulation, according to the Mason-Likar configuration [7]. The chest leads were not attached. Arm movements were captured using 9-IMU MetaMotionC units housed in a 3D printed housing. Data transmission to the PC was provided by Bluetooth Low Energy (BLE) technology [5].

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Simulator software

Car simulation software allows the creation of objects, traffic situations and their triggers [5]. At start-up, a specific driving scenario is selected by the physiotherapist, which sets the position of the car, objects, triggers on the given map. The monitored parameters, which include car position, car speed, position of controls, etc. [5], are stored. For precise synchronization, physiological and simulator data were recorded on one PC.

A sample screenshots of the city scenario are shown in Fig. 1 and Fig. 2. Driving scenarios and evaluated parameters are shown in Tab. 1.

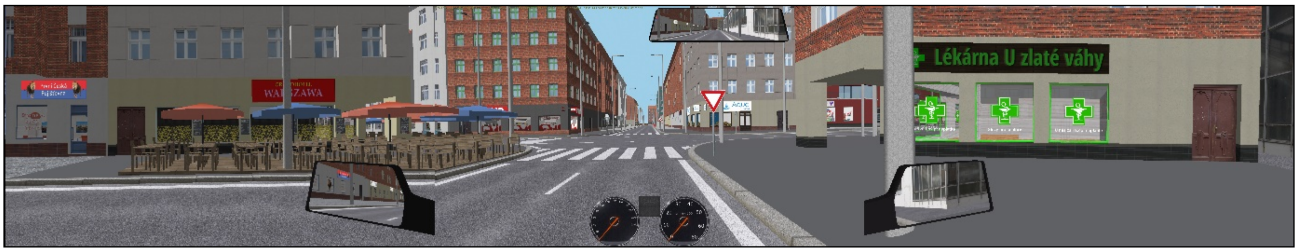

Fig. 1: City map – driver's view.

Fig. 2: City map – upper view.

Driving scenarios

Table 1: Driving scenarios and evaluated parameters.

Category	Scenario	Evaluated parameters	Recommended training
Motor control of the vehicle	1. Control test	Maximum steering wheel rotation, pedals depression	Car park 1 Car park 2 Car park – slalom
	2. Car park – instructions	Reaching the desired speed, turning at speed, stopping	
Attention and monitoring the area around the car	3. Highway – speed and direction	Reaching the desired speed, speed variations, maximum speed	Car park – slalom Car park 3 Countryside – straight Countryside – bridge Countryside – field
	4. Highway – neglect	Variation and ability to reach the desired and maximum speed of car, accuracy and speed of reactions	
Passage of the defined route	5. Countryside	Completion of the route, lane keeping, deviation from the ideal route by more than 2 m, driving speed	Car park – slalom Car park 3 Countryside – crisis Countryside – bridge Countryside – village
Traffic situations	6. City – driving priority	Whether all driving priority have been given correctly	City Training track
	7. City – main road	Whether all driving priority have been given correctly	
Complex abilities	8. City – car following	Whether the car was followed (not lost), speed of reaction (variability of the distance between cars).	City Training track Training drive uphill

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The individual driving scenarios were designed in collaboration with a traffic expert who identified the basic types of tasks and situations to be performed by the proband. At the same time, the scenarios were rated according to the level of complexity for brain injury patients. For these purposes, the opinion of the physiotherapist was included in the process of determining the level of complexity of the scenario. The monitored driving parameters of the individual driving scenarios are shown in Tab. 2–9. For each monitored driving parameter, the range for successful completion of the scenario is presented.

Table 2: Control test.

Monitored Parameter	Description	OK	!!!	X
Accelerator pedal (-)	Maximum accelerator pedal depression	1	-	<1
Break pedal (-)	Maximum break pedal depression	1	-	<1
Clutch pedal (-)	Maximum clutch pedal depression	1	-	<1
Steering wheel – left (-)	Maximum left turn	1	-	<1
Steering wheel – right (-)	Maximum right turn	1	-	<1
Button (-)	Pressing the round button (2x)	Yes	-	No
Overall rating: All **OK** – passed, 1 **X** and more – failed				

Table 3: Car park – instructions.

Monitored Parameter	Description	OK	!!!	X
Start the car (km/h)	Start the car at least at 5 km/h	Yes	-	No
Reaching the desired speed (km/h)	Reaching a speed of at least 60 km/h with 5% tolerance	Yes	-	No
Left turn (-)	Turning the steering wheel to the left while driving	Yes	-	No
Right turn (-)	Turning the steering wheel to the right while driving	Yes	-	No
Stopping (km/h)	Slowing the car to 0 km/h	Yes	-	No
Overall rating: All **OK** – passed, 1 **X** and more – failed				

Table 4: Highway – speed and direction.

Monitored Parameter	Description	OK	!!!	X
Speed variation during monitored section (km/h)	Difference between the lowest and highest	<50	50–61	>61
Time to reach 110 km/h (s)	Time of reaching the speed (after speed was higher than 2 km/h)	<37	37–41	>41
Maximum speed (km/h)	Maximum speed	101 – 119	90–100 or 120–130	>130 or <90
Overall rating: All **OK** – passed, 1 **!!!** and more – warning, 1 **X** and more – failed				

Table 5: Highway – neglect + Tab. 4 parameters.

Monitored Parameter	Description	OK	!!!	X
Reaction time to left side stimuli (s)	Longest reaction time to a stimulus from the left side	<= 1.1	(1.1–1.6>	> 1.6
Correctness of answers right side (-)	The ratio of correct and incorrect answers to the stimuli from the right side	1	-	>1
Overall rating: All **OK** – passed, 1 **!!!** and more – warning, 1 **X** and more – failed				

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Table 6: Countryside.

Monitored Parameter	Description	OK	!!!	X
Completion of the route (bool)	Completing the entire route	Yes	-	No
Lane keeping (%)	What % of the route was performed by the proband in their lane (i.e. X=more than 4% of the route was made off lane)	>98	96–98	<96
Relative speed (-)	**!!!** if the proband was driving slower than ½ of a group of healthy drivers, **X** if the proband overtook the car in front	0.5–1	<0.5	over took
Number of lane exit (-)	The number of exits from a given lane by more than 2 m	>98	96–98	<96
Overall rating: All **OK** – passed, 1 **!!!** and more – warning, 1 **X** and more – failed, **NaN** – in case of non-completion of the route				

The concrete numerical limits in Tab. 4–6 were defined to fit between first and third quartile for healthy volunteers.

Table 7: City – driving priority.

Monitored Parameter	Description	OK	!!!	X
Priority for pedestrian (bool)	Proband gave priority to a pedestrian in a crosswalk	Yes	-	No
Priority for cars at crossroad 1 (bool)	Proband gave priority at the first crossroad	Yes	-	No
Priority for cars at crossroad 2 (bool)	Proband gave priority at the second crossroad	Yes	-	No
Priority for cars at crossroad 3 (bool)	Proband gave priority at the third crossroad	Yes	-	No
Overall rating: All **OK** – passed, 1 **X** and more – failed				

Table 8: City – main road.

Monitored Parameter	Description	OK	!!!	X
Correct passage through crossroad 1 (bool)	Proband did not stop at the first crossroad	Yes	-	No
Correct passage through crossroad 2 (bool)	Proband gave priority at the second crossroad	Yes	-	No
Correct passage through crossroad 3 (bool)	Proband passed the third crossroad safely (not less than 3 m from the car	Yes	-	No
Overall rating: All **OK** – passed, 1 **X** and more – failed				

Table 9: City – car following.

Monitored Parameter	Description	OK	!!!	X
Car following (bool)	Proband has completed the route and has not deviated from the followed route by more than 5 m.	Yes	-	No
Overall rating: All **OK** – passed, 1 **X** and more – failed				

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Matlab GUI application

For the purpose of easier use of the simulator software and hardware, a Matlab GUI application has been designed. This application, shown in Fig. 3, allows the selection of a given driving scenario without the need to write to non-trivial parts of the simulator software. At the same time, this application allows the writing of the proband ID and the selection of the visualization of intermediate results that are displayed after the completion of a chosen driving scenario. Another feature of this app is the playback of audio files containing pre- and in-test instructions. Generation of the final report after all driving scenarios is possible.

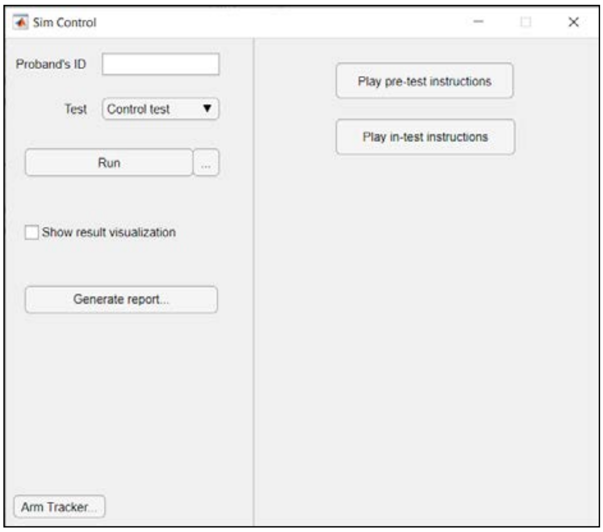

Fig. 3: Simulator control GUI application.

Methods for the evaluation

To evaluate the measured data, the analytical methods in time, frequency and time-frequency domain extended by nonlinear analysis were used.

Time domain evaluation was mainly used for the simulator data [8].

Frequency and time-frequency analysis was applied to gyro-accelerometric arm movement data [9, 10]. In this case, the resultant linear acceleration vector was evaluated [11].

A Poincaré plot was used to assess heart rate variability [12]. The distance between R-R intervals was determined using maximal overlap discrete wavelet transform (MODWT) [13] with preprocessing in the form of Sgolay filter to reduce isoline drift [14].

Results

An example of the Poincaré plot analysis is shown in Fig. 4.

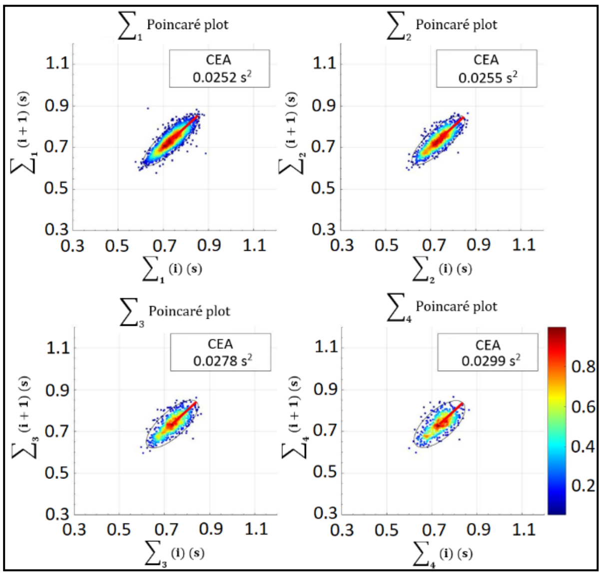

Fig. 4: Poincaré plot analysis.

The time-frequency analysis of the right hand movement within a 4-minute drive is shown in Fig. 5.

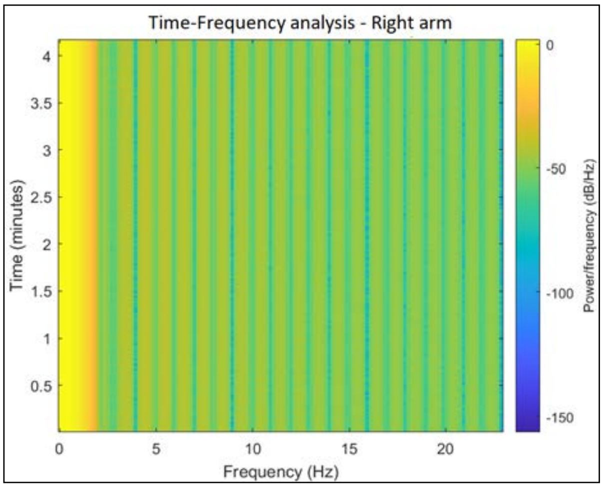

Fig. 5: Time-Frequency analysis: Right arm.

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Fig. 6 shows information about the position of the individual controls of the simulator and the speed of the car during the measurement.

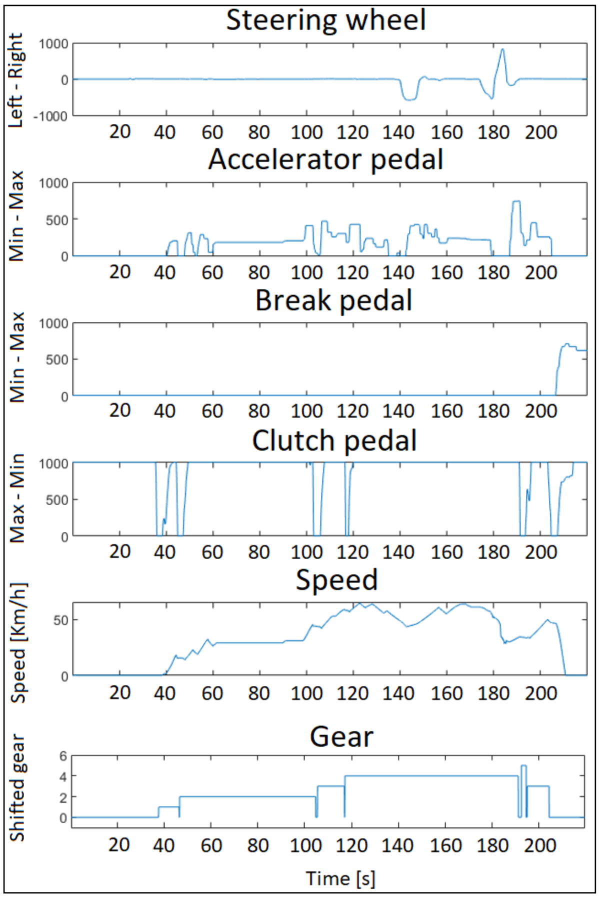

Fig. 6: Basic recording of simulator data during a Control test driving scenario.

Visualization of the distance of the car from other objects involved in traffic situations, including the positions of their triggers is shown in Fig. 7.

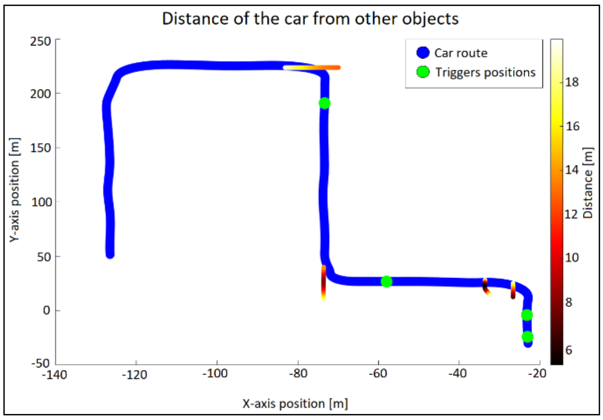

Fig. 7: City – driving priority.

Discussion

The Poincaré plot (Fig. 4) was used for the assessment of heart rate variability because of its easy interpretability. The purpose of this method is to evaluate the cognitive load during the different driving scenarios.

In the case of arm movement evaluation (Fig. 5), it seems unpromising to use the time-frequency evaluation, mainly because of the impossibility to detect small differences in acceleration during the measurement. A possible alternative method is the evaluation of SWM, which can be seen in Fig. 6.

Driving scenarios Test control (result visualization depicted in Fig. 6) and Parking – instructions show the motor control skills. If the proband has 1–2 errors, it is probably due to inattention.

Driving scenarios Highway – speed and direction and Highway – neglect are focused on attention and monitoring the area around the car. In addition to the ability to control the car (with emphasis on the ability to shift gears, which is necessary to reach the desired speed), these scenarios also assess the extent to which the proband is able to divide attention between the speedometer, lane keeping, and objects around the car.

Driving scenario Countryside is mainly focused on driving a defined route, i.e. testing vehicle control in light traffic (completing the route without crashing) and the ability to stay in the lane.

Driving scenarios City – driving priority (Fig. 7) and City – main road focus on evaluating traffic situations, specifically whether the proband can comply with traffic rules in the city. The scenarios are failed if the proband misjudges the driving priorities at least once.

The City – car following scenario is a bonus task, which the proband pass only if he/she can handle the City – driving priority and City – main road scenarios without major problems. The ability to quickly navigate in traffic and keep a safe distance from the leading car is assessed.

After passing the desired scenarios, the control application creates the report based on the limits mentioned in Tab. 2–9 in HTML format which can be opened in every Internet browser.

Conclusion

The information presented in this article may help in the future development of a methodology for measuring and assessing driving ability, especially in patients after brain injury, which does not yet exist. For this purpose, a test battery of driving scenarios with increasing motor and cognitive demands was developed. The main objective of the presented solution is to objectify the assessment of driving abilities, which is currently based on subjective evaluation by traffic experts.

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Suitable parameters to be monitored include steering wheel, accelerator and brake pedal movements as well as more complex tasks represented by the ability to maintain a prescribed vehicle speed and ideal route. Cognitive abilities and the ability to react to sudden change are mainly tested in city scenarios where the task is to follow the rules of the road. In this case, the use of Poincaré analysis parameters is appropriate as it can quantify the cognitive load and is easy to interpret compared to other non-linear analyses.

In future research, the assessment of specific complications associated with brain injury can be investigated, e.g. using the evaluation of a neglect or a reaction speed which are already implemented in proposed system.

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