Interactive Driving Simulators – History, Design and their Utilization in area of HMI Research

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***Abstract*—**The paper brings a comprehensive view on the topic of interactive driving simulators. Starting with history of interactive simulation it covers the problems of different simulation technologies and the simulator of various vehicles used for research tasks and training purposes. The further text is focused mainly on driving simulators construction and their use. In the next part there is described in detail an architecture of driving simulators and recently used technologies (including those, which were developed within our laboratories). This is illustrated on examples of the simulator systems developed and used within the research work of our institute and laboratories - Institute of Vehicles, Driving Simulation Research Group and Laboratory of Systems Reliability at the Faculty of Transportation Sciences of Czech Technical University in Prague.

***Keywords*—**driving simulation, history of simulators, HMI, simulators, training.

I. Introduction

MODERN interactive simulation of transport systems is set up as a model of the vehicle (or other machine). If the simulated operation of the device includes driver's interventions, it is a so-called simulation system "driver in the loop" or "operator in the loop".

Interactive simulation model and a vehicle are equipped with functional models of systems from the perspective of the user (operator) providing the functions necessary for a validity of a particular experiment or a satisfactory training. Since the model is a real system with limited capabilities, it is always necessary to assess with enough care (often based on many years of practical experiences) whether the simulator system is suitable for each particular experiment or training Moreover, sometimes also validation and comparative experiments are necessary.

Modern simulators usually consist of parts of real vehicles or machines, with which operators interact, and the complex system of computer-generated virtual reality, which should cover the widest possible range of operator's sensor input, so that it can induce a sense of realistic environment. The primary group consists of visual cues, audio cues and the dynamics cues (perception of self-movement). Other cues are generally neglected, if not directly related to the specific measurement or training.

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II. History and concepts of the interactive simulators

The very first simulation systems can be found at a beginning of air force pilots training procedure. Training in real planes meant higher training cost and high danger rate for novice pilots. After such successful launch of pilot training simulators, other vehicles simulators came quickly. The most widespread have become the car driving simulators.

The simulator systems used to be developed for use in three separated fields:

- Training
- Research
- Entertainment

Originally, different ways of use of the simulators in the above noted fields have merged during decades of their use and development.

A. Flight simulators

The flight simulators started the era of training simulators in the beginning of the 20th century. Flight training school "Antoinette" developed the first flight simulator early in 19th century and applied for the US patent in 1930 (Fig.1, Fig.2).

Fig. 1: Antoinette flight simulator in action (from [1])

B. Space vehicles simulators

Space vehicles are very special systems which construction is quite unique. Besides this, they are very expensive and their operation must be performed faultlessly. Any operator's mistake can have horrible consequences. Moreover, the training under real condition is almost impossible. From those above listed problems, the use of simulator is easy to come.

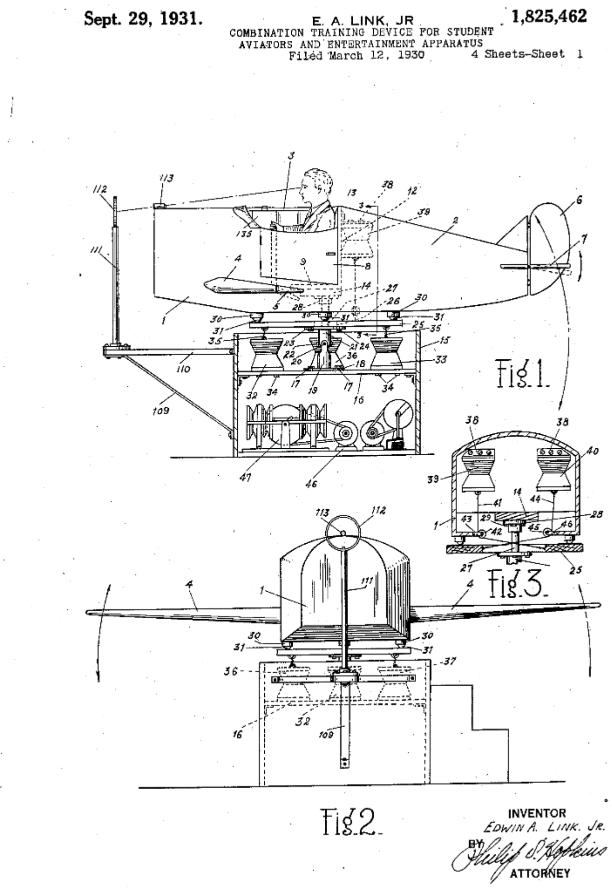

Fig. 2: Antoinette flight simulator – patted in 1931 (from [2])

C. Rail engine simulators

Rail engine simulators are often used in developed countries for training of engine drivers. This covers either novice basic training or so called "new track familiarizing" for experienced drivers being prepared for new lines. Such simulators can be differentiated into following categories:

- Rail engines (locomotives)
- High speed trains
- Trams
- Special railroad vehicles and machines

D. Captain bridges (ships) simulators

As in case of other expensive vehicles, the ship simulators are extremely cost effective. The next picture shows interior of captain's bridge training simulator used to train officers of Dutch Naval Forces Although the initial cost of the simulators is quite high, its working cost is incomparable to the real training ship (we must count also work of the whole ship crew).

E. Operator's workplace simulators

At the end of the 20th century development of traffic significantly increased, which led to a growing need to build terrestrial road communications as well. The construction of these roads has involved transportation structures such as bridges and tunnels.

Tunnels can be affected with numerous critical situations. The standard emergency situations can include failure of transport facilities and equipment related to traffic control. Other critical situation may occur when oversize loads vehicle entering the tunnel, an accident happens or automobile traffic congestion appears. Several times per year they needed to solve such crisis situations, such as car in the opposite direction, it may happen that there is observed a small fire in either a tunnel tube or technical background. Dispatchers must be ready for the extreme cases like tunnel fire or terrorist attacks.one of such simulators was developed in our laboratory [3].

F. Special devices simulation

In this group, we can find mainly the training simulators of devices to be operated in various industrial areas. These are mainly mine vehicle or drilling mechanisms or heavy cranes (in ports usually). Medical treatment simulators present a special category. There, "operators" (surgeons, nurses, dentists etc.) are trained how to deal with humans.

G. Driving simulators

Under the term of so called driving simulator, we consider the interactive simulator either of car (passenger cars, lories, trucks, heavy tippers etc.) or two-wheelers (i.e. motorbikes). The car driving simulators are discussed in more details thereinafter.

The interactive simulators of motorbikes are now mostly used for entertaining purposes or in the first stages of motorbike drivers training. This is due to the fact that the process of driving is slightly different from for example cars, where just simple rotating of steering wheel forces the car to move in suggested direction. The motorbikes require much more physical interactions to control the machine in appropriate way. This of course puts much higher demands on such responses of the simulator like correct motion cueing and possibility of rocking the machine left and right while turning. On the other hand, the bike, while moving thanks to interties and a gyroscopic effect tends to stay in vertical position. This is very hard to be simulated, in the way the riders would be feel like on the motorbike. However, there are now several research applications even for motorbike simulators.

H. Car driving simulators

The driving simulators and the driving simulation technology are said to be a "royal discipline" within the scope of the simulation devices.

The advanced driving simulators are very expensive. First, their technical and spatial demands are very high and second, they are not produced in large series, but mostly developed individually on demand. For this reason its development includes a lot of research effort (it is always expensive).

For the reasons described above, they are usually developed and designed in cooperation with university research institutions, state research institutions and car manufacturers.

The driving simulators are continuously developed in the majority of industrial countries over the world. Their detailed description would require a big amount of space, so this paragraph serves as an illustration only.

The first driving simulator was designed as 3DOF motion based one. It was equipped by one screen in front of the windshield. It was built by Volkswagen in early 70's. Having experiences from this motion based simulator in Germany, Swedish Road Administration (VTI) in 1977 started to develop a novel and complex design, which has majority of features of nowadays simulators (see next pictures – Fig. 3).

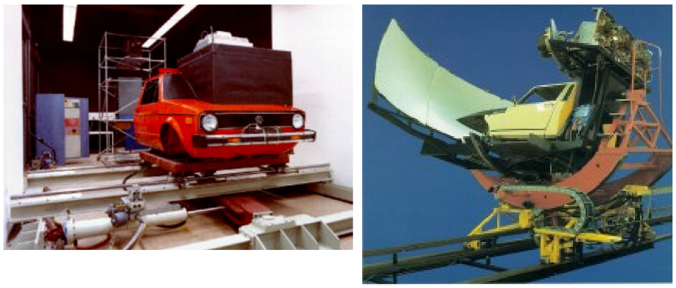

Fig. 3: The first motion based driving simulator VW (left) and its Swedish descendant from 1984 (right).

1) Non-interactive simulation

In the very beginning of HMI research history non interactive car "simulators" were frequently used. Basic research activities did not necessarily require simulating complex interactive behavior, but rather rely on predefined scenarios. In this case, the feel from real driving is usually simulated with use of car body or mockup and movie projection. Such simulator systems are still used mainly by psychologists.

2) PC "game" simulators

Such kind of so called serious games can be considered as simulators as far as they satisfy particular experimental conditions for validity. In other words any PC driving game can be used for either training or research purposes in limited cases. Thanks to the rapid development of gaming industry nowadays, these games usually offer stunning graphics but the realism is usually not their intrinsic feature as they rather offer entertainment.

3) Virtual simulators

Virtual simulators are in fact PC simulators which utilizes virtual glasses as an output and frequently also haptic feedback as additional outputs. Input is usually done via normal gaming steering wheel. This is mostly satisfactory since the "real parts" of the cockpit, the driver can see, are virtual ones.

4) Light cockpit simulators

Light cockpit simulators take advantage from the fact, that the driver usually does interacts with car cockpit in a limited range. This allows to surround him/her with important parts of the car and save space and weight (which is crucial in case of motion base setups). See Fig. 4 for reference.

5) Full body simulators

These simulators are composed of the whole car body (or partially cut off unnecessary parts due to spatial of weight restrictions). They are considered as a top version and are used with and without motion platform.

Fig. 4: Driving simulators by Mitsubishi Precision (Left) and Honda (Right)

6) Motion platform based simulators

The simulators with advanced motion cueing are based on several construction approaches. Since there is in most cases a whole car inside the simulator main body (dome), the most important requirement on moving platform is its adequate bearing capacity.

Full body simulators with motion platforms 6DOF. Most of the simulators that use full car body mockup are placed on the top of so-called Steward Platform or "hexapod". This system enables to simulate movements in all 3 axes and tilting in all 3 angles. Its main advantage is that they can make a full range of possible motion cues but their range and frequency is limited according to their size and payload. Hexapod construction comes from the field of aircraft simulation, which, maybe, from the first look seems to be more complex (since the aircraft is floating in the air). Unfortunately the situation with car simulators motion cuing is even more complicated due to the fact that the car is tightly bind via wheels to the surface of roads and it still requires regular movements and tilting in 6DOF.

Because of above described problems the hexapod construction is not agreed to be suitable for car driving simulators and it is usually extended to reach higher range movements or enhanced with additional motion actuators.

Full car body is placed on the moving platform enhanced with vibration actuators placed beneath the hubs. The simulation system is equipped with very large projection screens. Since the screens are static and the car mockup is moving independently, this setup is necessary to cover the driver sight even if the care is tilted. Due to this fact, it is also easy to come that the simulator is capable of limited range of motion cueing.

Full car body is placed on a hexapod with extended size. The visualization system does not need to be so large, because the car body does not change its position with respect to the projection screens. Visualization is frequently realized as a projection dome or a part of it (Fig. 5).

Full car body is placed inside pensile capsule which is hinged by "giant" hexapod installed upside down. This solution is unique and its architecture advanced the hexapod system with possibility of simulation of lateral movements that are quite limited in conventional hexapods.

Fig. 5: Full car simulator situated on robust hexapod platform in BMW – left and one of the European latest simulators in DLR – right

To simulate realistic feeling from driving it is necessary to assure that the driver is exposed to at least basic spectrum of motion cues. These are beside acceleration and deceleration also centrifugal forces acting on the driver when the car is turning left or right. In certain limited range, it is sufficient to cheat the driver with rocking the car left and right according to the steering wheel movements as it is done for the case of speed up and down changes. However, the driver when controlling the car direction relies on lateral acceleration and motion as a direct response to his steering maneuver. For this case, it was proven that lateral movements are the most appropriate motion cues.

Because of the above described facts, the most advanced motion based driving simulators are often designed as a mixture of motion cueing approaches:

- motion (vibration) actuators with limited range mounted under each of hubs
- hexapod with medium range supported car body and frequently also visualization screens or dome
- cross platform on which the complete system made of both above mentioned parts is moving in XY direction to simulate lateral and longitudinal motion cues

See Fig.6.

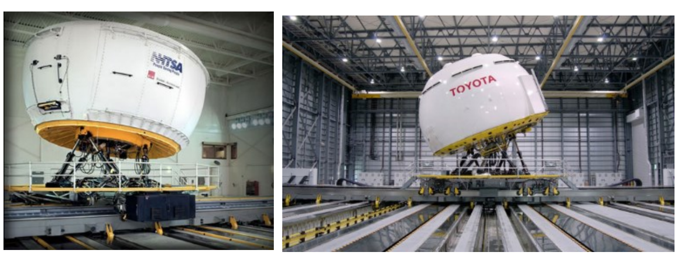

Fig. 6: Perhaps the most advanced motion based simulation systems – NADS in USA (left) and Driving simulator Toyota in Japan (right)

III. Design of Driving Simulators

As it was possible to see from the previous chapter, the simulators have different construction topologies. The topology is often connected with the simulation fidelity but they are tightly coupled with the system cost. Although the simulators producing the majority of available cues in the largest ranges are considered as high fidelity simulators, they do not necessarily fit best to all experiment types. Even the most expensive systems still only approximate the real driving experience. As a result there is only a model more or less satisfying needs of each particular experiment.

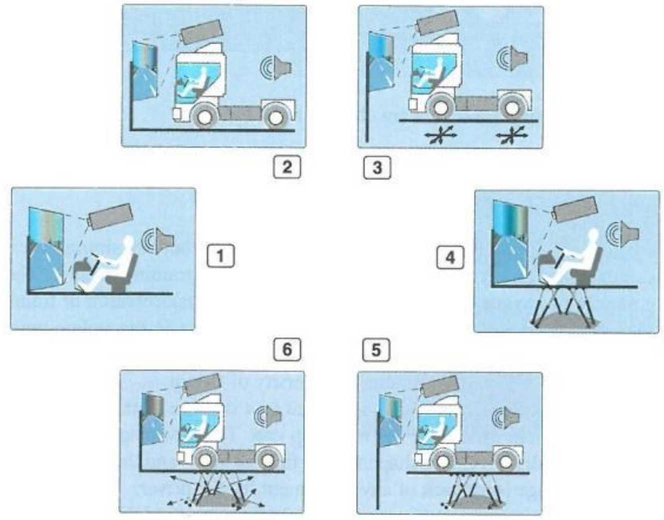

Fig. 7: 6 basic driving simulator setups 1-6, as described in the previous text (adopted from [4])

Generally, nowadays simulators can be differentiated into 6 basic topological setups. In the next picture (Fig. 7), there are illustrations corresponding to setups in order based on approximate cost (from cheapest to the most expensive).

Several different variants can utilize more than one topology from those above described. Alternatively, they can have features, which are not covered with such categories.

A. *Architecture of the system*

Modular architecture - in fact, the architecture of the simulator itself is usually modular. The basic system setup can be decomposed into subsystems, which could be treated and solved separately (see the diagram Fig. 8). [7]

The modules can be treated and operated separately but it is very useful to take advantage of their interconnection. The results from tasks computed on one particular module could be utilized in other modules, which process the same (or very similar) data. As an example, we can consider a geometric representation of an area of the virtual scenery. The graphical engine primarily cuts off an appropriate area of the virtual world representing the actual driver's surroundings. Then the geometry should be worked out according to a particular level of detail. Such data then enter into rendering process. Such data could be also reused in other modules. For example, the audio system also needs the geometrical representation of the world to be able to render the sound realistically. Other modules, which can take advantage from such pre-computed data, are for example:

- collision detection subsystem
- traffic management subsystem
- general output subsystem
- car simulation physics engine

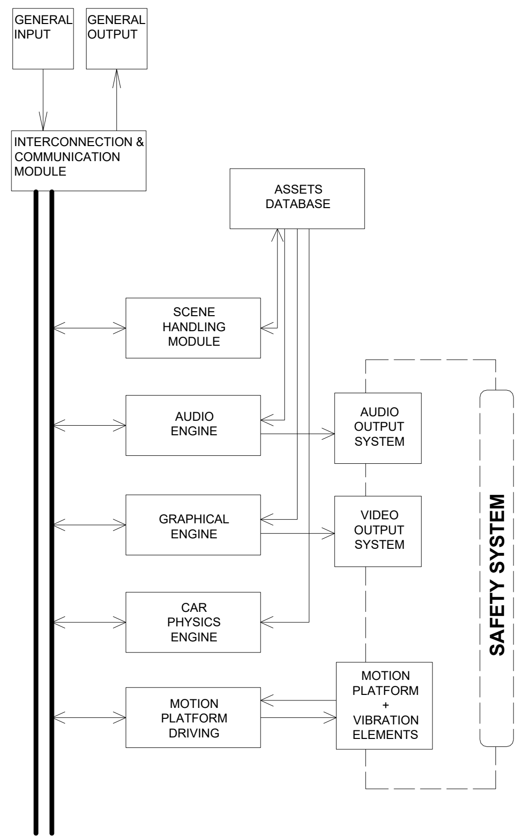

Fig. 8: Advanced driving simulation system – basic modular structure

B. Mathematical – Physics simulation engine

The model of the car is created with the use of linear integral-differential solver. Online processing of input data (signals from the devices representing driver's controlling actions) is a basic Gear shifter position requirement on mathematical model of physical behavior of any interactive simulation system. Such inputs, in case of driving simulators, are represented by the following signals (parameters):

- Rate of depression of throttle pedal
- Rate of depression of brake pedal
- Rate of depression of clutch pedal (in case of manual gear shifting)
- Angle of steering wheel deflection

Those are the basic ones, which can be (and in most cases of high fidelity simulators are) accompanied with additional inputs which tell the simulator about the driver's orders and wishes (handbrake, handlers, buttons etc.). The physical "engine" (processing the mathematical car model) should be able to react on additional inputs which are usually realized via direct (manual setting) or indirect (realized via activation of some assistant system) driver's interventions.

Another important source of information upon which the mathematical model decides about future steps in car behavior is an actual state of the objects the car is interacting with. Upon these above described information and information about inner structure of the simulated system (axle architecture, gearbox etc.) the actual behavior (next step) is computed. [9]

C. Visualization system

Most of the information that the driver's brain needs for driving (i.e. correct response to the outer conditions and various stimuli) are visual ones. From the observed virtual scenery, the driver gathers information primarily about:

- Shape and color of the surrounding objects (including the road)
- Distance of the objects
- Self-movement (eventually the relative movement of other objects)
- From those primary cues, he/she derives secondary information about:
- Self (car) velocity in all directions
- Limited range of self (car) accelerations in all directions
- Weather conditions
- Road condition
- Surrounding objects (obstacles) and their movement
- Surrounding traffic
- Contextual information (signposts, pictograms, texts, traffic lights, etc.)

1) 3D projection

The driver should obtain correct information about his/her distance from outer objects. A standard projection simulates depth by correction of vertical and lateral coordinates by the portion of depth coordinate, so that there is an effect of "distant junction of parallels".

A stereoscopic projection gives the solution to this problem. Two main ways most frequently used (anaglyphic glasses are used really):

- Polarizing filter glasses (passive stereo) - a cheap method that transports correctly the appropriate image into the appropriate eye, based on two differently oriented polarizing filter couples.
- Shutter glasses (active stereo) - an approach is based on principle of shutters synchronized with graphical output providing for each of the eyes only the appropriate frame. Their shutters are frequently limited in size.

D. Audio system

Besides the visual information, the second most important one is the sound information. It accomplishes or substitutes the visual and other cues coming into the driver's senses. From the virtual sound, the driver can get information about:

- Car velocity
- Engine velocity and load
- Interaction with different types of road surfaces
- Sound properties of surrounding environment (open road, tunnel, corridor, bridge, forest, etc.)
- Surrounding traffic
- Collisions

The car engine sound is one of the most important audio stimuli for the driver ([4]).While driving a real car, the engine is not usually the strongest source of the sound, but it is important for the driver to feel how fast the car goes and how fast the engine rotates. Besides the hearing and the visual sensation there are the haptic perceptions, which cause the feeling of speed. The rumble of moving car is carried from the steering wheel to the driver's hands, and also to the whole body via the seat and the car floor. These are also very important noises but they are hard to simulate. In the driving simulator it is convenient to simulate much more clear, strong and sharp sound than is present in a real car, especially if it is not possible to simulate haptic perceptions. The audio perceptions partially take over a task of haptic ones, which is very beneficial.

E. Steering wheel

The system that is necessary to be emphasized is the feedback on the steering wheel. This 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.

F. Haptics, motion cueing

Both of the frequently used simulators - the steady based or motion based - can be equipped with additional feedback devices. They should provide even more realistic feelings from driving. The aim of their use is to stimulate mechanical feedback coming either from the car itself or from the environment (e.g. road, blasts of wind). Motion platforms used in modern simulators are quite complex, mainly from the point of intelligent control, which should give the driver mechanical (based on forces acting on his/her body) responses from driving, utilizing only limited range of accelerations.

IV. Driving Performance Assessment Tools

The aim of the tests is the objective assessment of user interface quality, human-machine interaction reliability (correctness, information understanding), positive virtue of the provided assistance and severity of possible negative impact (secondary load). Measurement (recorded data) on the vehicle simulators can be divided into two elementary groups, the objective measurement and the subjective measurement.

The objective measurement can further be divided into technical data, measured directly on simulator and data related to the measured object. The simulator outputs (technical data) are included in the objective measurement data set, it is mainly the speed and vehicle trajectory (the deviation from ideal driving path or road center can further be calculated) and engine revolutions. Technical data include as well the depression of pedals (accelerator, brake, and clutch), gear or steering wheel movement.

Except of these purely technical data, additional measuring equipment (sensors, detectors) can be located either on the vehicle simulator or experimental driver (proband). The output of this equipment is included in the objective measurement data set; they consist of biological data as ECG record, pulse or eye movement record. Reaction time to various impacts, head movements and camera record can as well be included in this group.

Subjective measurement is represented by e.g. questionnaire analysis in which the drivers describe their state before and after simulator driving or their feelings and notes from the drive or they assess various aspects of the tested user interface.

The following picture (Fig. 9) explains in a descriptive way the division of various types of measurement that can be performed using the simulator.

When assessing the experiment, the technical and measurable psycho-physiologic features are the most focused ones. The following are observed above all:

- Reaction time to notice the warning
- Reaction time to assess the information
- Appropriate assessment of the acquired information
- Driving parameters objectively describing the driver's secondary load
- Psycho-physiologic output objectively describing the quality and driver's secondary load
- Stress
- Tiredness

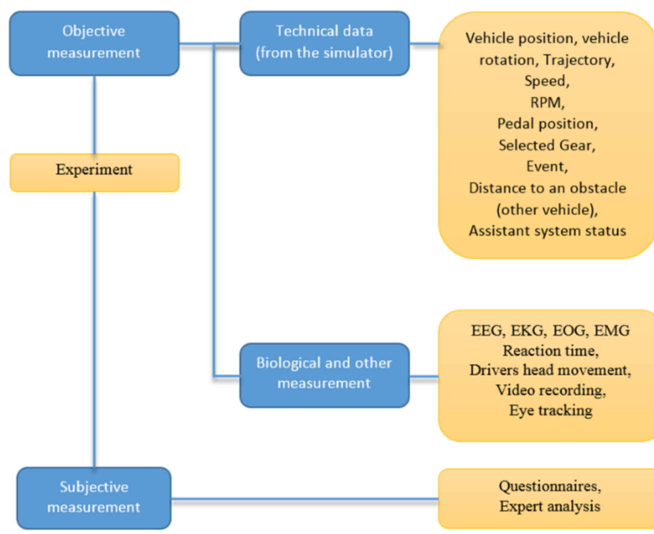

Fig. 9: Diagram of measured data

Possible approaches of the data classification with respect to driver's performance were published in several our research papers (e.g. [8,10,11,12]).

A. Data assessment and classification

Steering wheel movement and variability – the vehicle location in relation to the driving lane axis is determined by the second integer of the wheel rotation angle, thus steering wheel angle. A series of experiments proved that the tiny corrective steering wheel movements change according to the rising level of driver's tiredness. The parameters observed in this method can be e. g. the speed and number of corrective movements, number of respective actions, change of corrective action speeds etc.

Transverse location of the vehicle – measurement derived from the vehicle location in the driving lane. This method, similarly to the others, is based on the presumption that the driver loses performance as his tiredness grows what can be apparent even in his driving style. Therefore the vehicle trajectory within the driving lane and its changes are observed in this method. This method was proven as capable and usable for prediction, as well as identification of driver's performance drop. The observed parameters of this method are: global maximum, standard deviation variance, dynamics of driving lane position change, corrective action frequency etc.

Transverse location standard deviation – number of studies performed on simulators show significant rise of transverse location standard deviation with the drop of driver's performance (tiredness). The transverse location standard deviation is in close relation to the probability of driving off the lane.

Time to crossing the lane – time to cross the lane (TLC – time to line cross) represents the time in which, under the stated conditions, any part of the vehicle crosses the road edge. This time is calculated using the transverse location of the vehicle. Many authors see the TLC to be the crucial measurement of driver's performance. TLC is often used to foresee the deterioration of driver's ability to drive caused by tiredness. Low TLC values describe ingoing tiredness and can warn the driver before the vehicle crosses the lane.

B. Possible analyses of psycho-physiologic data

Eye closing observation – this method is based on the measurement and assessment of time, during which the eyes are "closed" or "opened". One of the typical features for this method is so called PERCLOSE, the "open" to "closed" time ratio. This method was proven as a useful method to assess driver's tiredness.

Eye movement observation – this method is based on the eye movement assessment. The reason to observe eye movement is the fact that slow eye movement is one of the signs of sleep. The eye movement characteristics (Slow Eye Movement - SEM) changes in respect to the tiredness level, thus eye movement represents one of reliable signals notifying the change of the state from awake to asleep.

Muscular activity – the method is based on the presumption there are several signals of sleep activity, low muscular activity or muscular tension especially in face and neck muscles among them. The facial expression is examined in this method, as the driver's face expression shall change with the rise of tiredness. The muscular activity is observed as well, since they cause the change in facial expression.

Brain wave activity – the method is based on the fact that the sleep is accompanied by significant changes in the amplitude and frequency of the brain signals. These changes can be recorded by the EEG (Electro Encephalograph). During significant drop of driver's activity even the EEG shows slowdown of brain activity, usually accompanied by rise of alpha and theta waves and on contrary drop of beta waves. This methodology is quite reliable, but at the same time very demanding, especially due to the need of "installation" of a number of electrodes on the driver's head, installed with reliable contact with driver's skin, acquisition of very low potentials (in μV) from the head skin and especially very demanding assessment of the measured values.

Heartbeat rate change – dependence of heartbeat rate and driver's tiredness level is long time proven. This methodology can be fruitful on its own with difficulties. It is mostly given by the fact that any movement or impulse can lead, and mostly leads, to change of heartbeat.

Skin potential – the method is based on the principle of skin potential measurement. It was experimentally proven that there is a significant correlation of skin potential and "alertness level". The main difficulty of this method is the influence of mood, activity level and temperate on the skin potential.

V. Simulator Systems developed at FTS CTU

Car simulation devices (FIDS – fully interactive driving simulators) are used and they have been continuously developed within the Laboratory of Systems Reliability (LSR) for more than eight years. We use several different versions (or types) of car simulator design.

A. Non-interactive simulation for rail engine-drivers

These kinds of simulators are still used mainly by medical institutions. We used such arrangement for sleep onset detection with the use of EEG. Railway drivers were tested just in front of the screen shoving a record from the regular line.

B. PC simulator

The very first arrangement of our simulation device used a common PC steering wheel with two pedals with a sequential gear shifter (or automatic shifting was applied). Now we use a special three pedal system (including a possibility of involvement of the clutch if required) and an H-pattern gear shifter. The realistic three-dimensional cockpit lets the driver immerse himself into the projected scene. In the picture (Fig. 10) there is depicted our very first approach to the driving simulation technology. The experimenting driver uses a big TV screen and common game steering wheel and pedals.

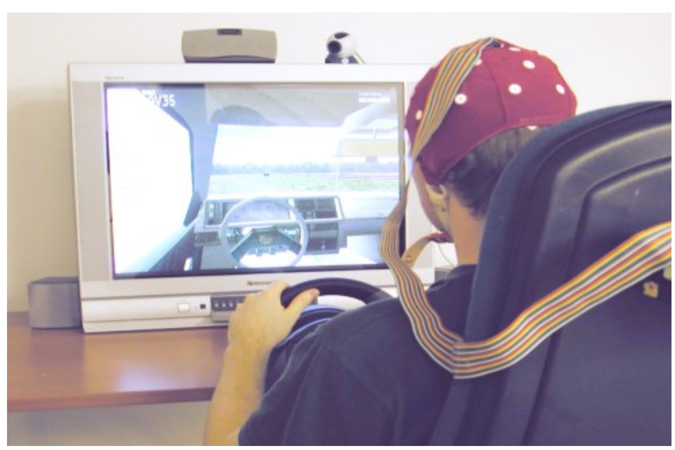

Fig. 10: The first PC simulator in 2002

The simulators being described in the next paragraphs are in detail described in [7].

C. Light (cockpit) simulators

This arrangement represents an intermediate step between the virtual conception and a usage of a real car body. It comprises advantages of both of these approaches. For example it is much more convenient (in comparison to the "compact simulator" discussed in the next section) for the implementation of so called "in-car dynamics", which forces the driver to percept the driving experience more realistically (see Fig. 1).

The simulation engine of the car is connected to the car parts via the CAN bus. Connection into CAN is bidirectional; functional parts are the speed and RPM needles (plus other information on a central display), a steering wheel, a gear shifter, a throttle and other pushbuttons and handles.

1) Light (generic) truck simulator

The following picture (Fig. 12) depicts a truck light simulator, without movable platform, which can be just enough to assess the ergonomics of HMI equipment. The most important parameters are the effective visual field and mirrors as the examined system shall be active at low visibility and worsened view conditions.

Fig. 11: One of the first prototypes of out light simulator (2003) – UPPER- and contemporary look of our light simulator Superb (2007) – BOTTOM

Elementary parameters of simulator:

- Driver's workplace.
- Fully surrounding projection with three full-HD screens and back mirrors in virtual scene.
- Virtual, resettable dashboard.
- Manual gear with clutch – automated as alternative.
- 3D stereoscopic visualization possibility.
- Fixed platform.

Any scene can be simulated from the point of view of the truck/bus. The view of the driver can be set as well.

2) Advanced 3D light simulator

It is based on cockpit of Octavia II. It offers cave-like visualization system enhanced with polarized 3D projection. The light version of the simulator is based on cockpit parts cut just behind the driver seat. The cockpit is fully equipped like normal car (including roof, mirrors, co-driver seat, etc.). The simulator system is placed on specially designed 3 DOF moving platform (Fig. 13).

Fig. 92: Light simulator of the truck

Fig. 13: Cockpit of the light simulator Octavia II 3D (2010) equipped with 3DOF moving platform, specially designed for use with light simulator

D. *Full body simulators*

This version is closest to the reality concerning the driver's ergonomics because it uses a complete real car body. The tested person sits in a real cockpit and the virtual scenery is projected on the screen walls in front of the car hood and/or around the car depending on the particular design. Results from measurements using such a device should not be loaded with an error caused by the difference between a simulator and a real car cockpit. On the other hand, this setup is rigid and very hard to reconfigure (for example when the experiments require several different configurations of function buttons handlers and/or dashboard instruments).

The full body simulator with all-around with 5 bended screens and LCD is based on the compact middle class car Skoda Superb (Fig. 104) equipped with an automatic gearbox. The projection screen of the simulator is cylindrical, covering about 210° (horizontally) of the driver's frontal field of view. The tested driver is surrounded by an almost complete, all-around image of virtual reality. Such an arrangement maximizes immersion into the testing scenarios and consequently the validity of the measured data.

Fig. 104: Driving simulator SUPERB (2003-8)

1) Training truck simulator 6DOF

The simulator with a movable platform is often – especially due to the cost of the moving system – designed as full mission simulator, or with the widest range of available impacts. Therefore it is apparent the driver's view is efficiently covered (Fig. 15).

Elementary features of the simulator are:

- A complete cockpit
- Fully surrounding projection with 16 full-HD projectors and in-scene virtual back mirrors
- Automated gearbox
- Optional 3D stereoscopic visualization
- 6DOF movable platform

E. Fully Virtual simulator

The use of VR in product design significantly reduces the production cycle, cuts cost and improves quality. Because there is no need to produce expensive physical models, their use is fast and very cheap. The experimental driver, equipped with head mounted displays (HMD), has now a freedom of view, which of course requires the cockpit completely modeled in 3D. A sensor connected to his head scans the driver`s head turns. This data primarily serves for evaluation of turn/move of the projected picture or it could be stored for further analysis of driver's head movement. Such a set up presents a good competition to a compact simulator because it could retract the observer deeply into the scene. The cockpit design, ergonomics or other setups could be relatively easily changed (tuned up), respecting the requirements of the actual experiment.

Fig. 15: The full simulator of the truck placed on hexapod platform (UP) and the view from its cockpit (BOTTOM)

Fig. 116: The driver inside virtual simulator (UP) utilizing high resolution HMD and motion sensors based on IR light reflections and corresponding driver's view (BOTTOM)

In the picture (Fig. 116 – UP), it is possible to see image the driver observes in HMD. Drive's hands are observed by IR motion tracking system and right hand fingers are connected to sensor glove. Thanks to such arrangement, a driver can interact with elements of virtual world. Except of interaction with basic cockpit controls (steering wheel, pedals and gear shifter), he /she can also touch other virtual buttons and handlers. In the following picture there is a real driver sitting in a virtual simulator trying to manipulate with inner middle mirror (Fig. 116 - bottom).

VI. Conclusion

The simulators give a wide range of possible applications. Nowadays, the high quality simulators are widely considered as valid devices for training of drivers, training situations under demanding conditions for professionals, but also for research and investigations concerning the reliability of driver-car interaction, for solving the large variety of human-machine interaction problems (HMI) and assistance systems optimization (for instance [13,14,15,16,17,18,19,20,21], etc.).

Driving simulators have been successfully used for several decades in research and automotive industry. We can find first steps of these activities in the 1950's (VW, BMW and Ford). Their blossoming appears in the 1970's (mainly Ford and VW). Originally, they were developed to help drivers to train their driving skills, and during time, they maturated for use in training of professional drivers of special vehicles to adapt to demanding situations.

During almost a decade, this research blossomed out rapidly and the original experimentation split into more than one discipline. Beside the original research activities investigating the operator drowsiness, now we have several branches covering the whole field of so-called HMI discipline.

Acknowledgment

The photographs of simulators (if not specifically written) are copied from publically available materials published by their respective producers/users or these are images depicting author's/author's team own work. This text is based on results of numerous predominantly national grants and commercial projects solved at author's institute during almost last 15 years. This includes enthusiastic work of his colleagues as well as participation of bachelor, master and doctoral degree students.

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