Hybrid mirrors for driving simulators – design, construction and experiments

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Abstract: - This paper introduces technology of so called hybrid mirrors incorporated in the system of car driving simulator. It first summarizes general requirements for the simulator visual systems from the point of view of a driver's complex visual perception and states the basic requirements for car rear mirrors visual system; it considers different variants of its implementation. The main part of the paper describes and illustrates an implementation of such system within our full-bodied car driving simulator. Finally an experiment utilizing such enhancement documents in vivo this approach.

Key-Words: - Driving simulators, simulation fidelity, virtual reality, driver's reaction time

1 Introduction

Driving simulators are successfully used in the wide field of human-machine interaction (HMI) discipline. They are used either for driver's training or research purposes as well. Nowadays, the high quality driving simulators are generally considered as valid devices for drivers' training, training situations under demanding conditions for professionals, but also for a research and investigations concerning the reliability of driver-car interaction, for solving the large variety of human-machine interaction problems and car-cockpit and assistance systems optimization.

Their theory, methodology of use, design, construction and operation require a very wide range of knowledge, from neurology, psychology, control engineering electronics, informatics, mathematics and mechanical engineering to transportation sciences.

We use the driving simulators for many years mostly for the research purposes. During last four years of work we have done plenty of experiments concerning investigations in so called "driver-car interaction" [2] (a special case of HMI [7]) with more than 500 experimenting persons. The main focus of these experiments can be divided into three main directions:

1. Fatigue related experiments [3,6]
2. Assessments of influence of HMI devices (IVIS) on driving safety and comfort [8]
3. Influence of environment on the driving safety [1]

The fidelity 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.

2 Driving simulator design

An overall system of 'living' simulator (equipped with tools enabling its modifications respecting actual needs of each particular experiment) can be described by a multilayer model. The next figure (Fig. 1) introduces the functional structure of our equipment from the point of view of the simulator.

The whole system can be divided into four layers (they are separated with green lines on the picture). The first layer represents the simulator device itself. It consists of software and hardware parts. As the hardware of our simulators we consider cockpit which is composed from parts of a real car and PCs connected to a network. I/O cards (like CAN bus to PC interface) are also included in this layer. Software of the simulator consists of Virtual Reality engine (generation of 3D graphics and spatial sound) and the physical engine. A real behavior of the simulated car is a necessary condition for good results of experiments. For that reason it is necessary to pay big attention to the realistic behavior of the car. The physical engine is always a compromise between a very accurate physical behavior and a very fast (real-time) response.

The next layer represents a database of testing tracks (sometimes called scenarios) and cars. Each experiment requires a more or less different scenario. To get objective results it is necessary to have precisely defined difficulty of each scenario. Sometimes we need a curveted road to study driver's ability to keep the car on the road while he/she is forced to fulfill an additional task. On the other hand a scenario for investigation of driver's drowsiness and fatigue is recommended to have a very boring (almost straight) highway road which cannot divert him/her but it let the driver to get into relaxation state. By the same way we should treat with the database of cars. Strong engine with automatic gearbox is suitable for measurement of drowsiness meanwhile a car with manual gearbox and weaker engine with worthier grip serves better for classification of one's driving style and so on.

The last layer represents tools for creation of assets constituting scenarios. Those are mainly modeling of 3D objects and tools for automation of such a process and databases (storages) of modeled objects. Each object in virtual reality is accompanied by a texture or a set of textures. The texture is a picture which simplifies the 3D object creation in following manner: The geometry of any real object is very complex, on the other hand it is possible to replace it with a very simple geometry covered by a worked out digital photography (texture). The textures can be of different types; general which are tillable (i.e. repeatable - like grass, road surface…) and the unique ones (houses, signs….). The amount of textures over one scenario could be very high but lots of them could be reused on several different pieces of geometry. For that reason it is also very practical to have apart the database of 3D models (objects) also a database of textures.

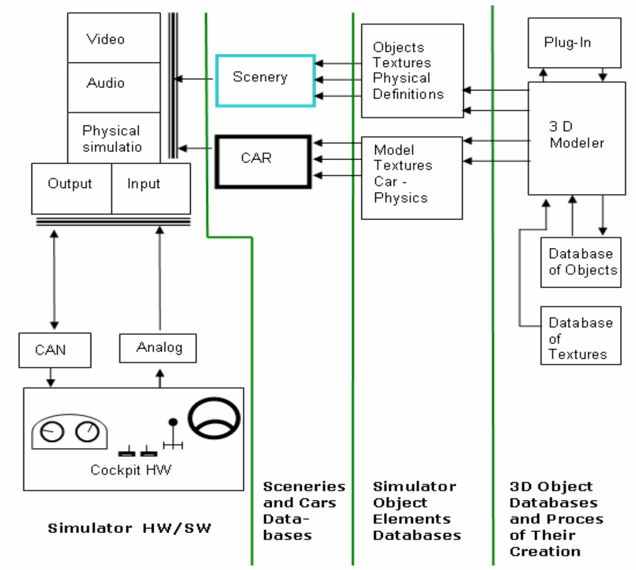

Fig. 1: Functional structure of the car driving simulator

3 Visual perception

A development of driving simulation can be considered as a multidisciplinary task, which encompasses a spread field of possible investigations.

Most of the information which the driver's brain needs for driving (i.e. correct response to the outer conditions and various stimuli) are visual ones [5]. The driver 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 motion (eventually the relative movements of other objects)

From those primer 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 movements
- Surrounding traffic
- Textual information (Signposts, pictograms, texts, traffic lights, etc.)

3.1 Projection of the virtual picture

Generally, it is desirable to provide the driver with as wide angle of view as feasible. Ideally the projection should be fully surrounding the driver [4]. On the other hand, drivers most of the time do not pay the same amount of their attention on all parts of their view. In fact the driver of a car does not directly look over the whole surrounding. Driver's view in the simulator (as in the real car) is shielded by the coulisse of the car cockpit.

Fig. 2: Our driving simulators with 5 projection screens covering 210^{o} of driver's view

The primary information which the driver perceives via visual input is what he/she sees on a frontal projection screen. In principal this information is satisfactory for majority of experiments. Mostly it is accompanied with two or more side projection screens (placed under different angles with the frontal one) which simulate a peripheral vision, useful mainly for self-speed perception and for tasks where driver should look around his/her car. Although, the side projection significantly increases the overall fidelity of the simulation, common drivers (when driving a real car in a real traffic) spend most of the time watching the scenery just in the front and overlooking the situation behind their car via rear mirrors. This fact proves that the realistic simulation of the rear mirrors plays a very important role within the scope of overall fidelity of driving simulators.

4 Virtual mirrors

Besides of the facts described earlier, testifying for need of realistic rear mirror simulation, it is necessary take into account driver's actions which strictly require rear mirrors to be implemented. They are essential for:

- Better identification of the self driver's (and consequently car) position on the virtual road
- Watching of the surrounding (and mainly tail) traffic.
- Parking / reverse driving.
- Overall level of immersivity of the visual system

The mirrors within the driving simulator systems could be realized in several ways, they differ in financial and spatial expenses and off course quality of the perceived picture. Those approaches can be divided as follows:

- A conventional method which utilize real mirrors in combination with fully surrounding scene projection. This solution is expensive and problematic with rounded projection screens. It is worthless when the simulator mockup is moving (mainly rotates) inside projection dome.
- Small LCDs placed inside real mirrors frames. They are relatively easy to implement; their cost is relatively low. This approach has two main disadvantages: First the resolution of small LCD displays is generally low, second they cannot take into account movement of parallax planes when an observer's head is moving (this is possible only with a help of special head of eye tracking hardware). Moreover, such image does not have that known "mirror-like" look.
- Hybrid mirrors – they combine LCD and real mirrors approaches.

5 Hybrid mirrors

This solution inherits advantages from both above described solutions. It is cheep, not demanding for a space and on the other hand it provides the driver feel of parallaxes movements as the full projection can give. Over more it can be realized with the very high image resolution for relatively low price (compared to the high resolution projectors which cost is higher in order of magnitudes) – the visual system which we used is capable of 1440 pixels in width for example.

5.1 Problem of parallax planes

In fact the final transformation of the 3D world is computed according the distance between the object and projection screen according to the projection axes centered usually in the middle of the picture. Unfortunately they cannot easily reflect the changes in observer's axes and angle of view. The more distant the projection cutting plane, the lower effect of inadequate parallax movements. The following sketch (Fig. 3) shows the movement of projected parallaxes behind the car using projection screens (the left light-blue line) and LCDs (light-blue boxes in the middle).

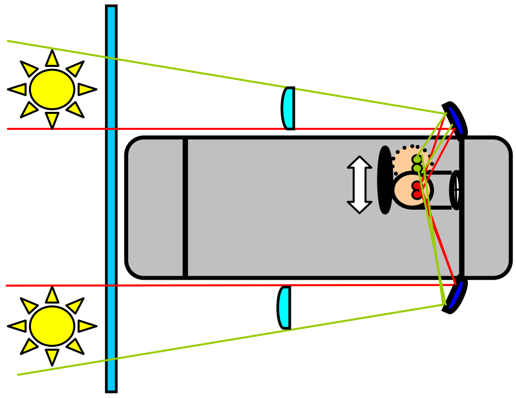

Fig. 3: Schematic diagram showing the problem of parallaxes movements when the driver moves his/her head. The driver's head movement is indicated by a white double arrow.

5.2 Design

Since our simulator structure is modular and scalable implementation of mirrors is not a complex task in its principle. The main virtual reality computer generates all the information (changes based on the interaction with driver and surroundings of his/her image with the virtual reality) and broadcasts it over a LAN. All the visual computers (utilizing SGI Performer visualization application) show their particular cutoff view of the scene with appropriate view angle. A similar approach was used for the mirror visualization.

5.3 Construction

The construction of our mirrors is illustrated with a set of following pictures (Fig.4 to Fig.7) on the background of hexagonal 210^{o}. We used three high resolution LCDs (one 24" for the middle mirror – placed behind the driver and co-driver seat- and two 22" ones for side mirrors). Special adaptable stands (and suspension inside car) had to be constructed so that the particular images fit into the each mirror. Pictures Fig. 5 and Fig. 6 show an implementation of the system with virtual semaphores appearing in the rear mirrors.

Fig. 4: Implementation of the right rear mirror

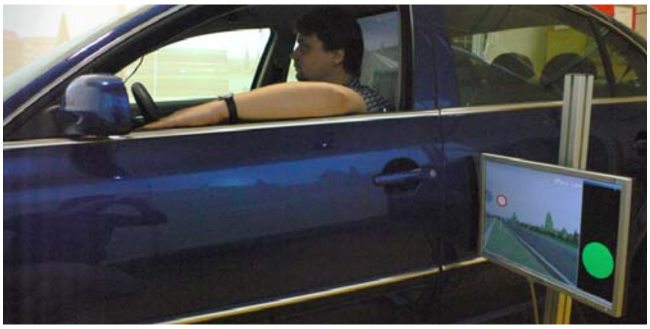

Fig. 5: Implementation of the left rear mirror – it is possible to see the projected picture with semaphore (see the chapter concerning the experiments)

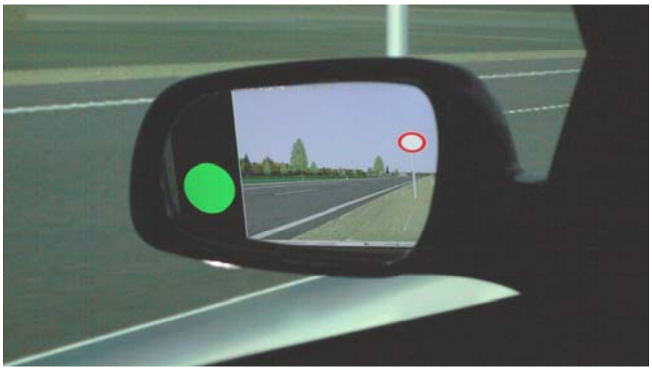

Fig. 6: Deriver's view into the left mirror – including the semaphore (see the chapter concerning the experiments)

Fig. 7: Driver's view into the middle (inside car) mirror

6 Experiment

To approve quality of the solution we built, an experiment utilizing was performed. This experiment is one of the first ones which intentionally utilize the rear mirrors of our driving simulators. The pilot experiment starts the series of measurements which are focused on the investigation in general issues of car driver's field of view. This project will study different aspects of driver's field of view related to the useful field of view (UFOV), speed of response on different stimuli, influence different sources of distraction etc.

6.1 Purpose of the experiment

Main purpose of this initial experiment was to prove differences between speed of the reaction to the stimulus appearing in the left and right rear mirror (central mirror was excluded from those initial measurements). Its results will be used as a background for the experiments investigate possible replacements of conventional mirrors with alternative sources of visual information what happens behind and aside the car.

6.2 Experiment procedure

Experiment was preformed with eight testing drivers. They all were non professional active drivers; their age was in between 21-32 years. They drove for approximately 30 minutes with several adaptation rounds (although they all were experienced with simulator driving). All drivers were requested to hold the steering wheel with both of their hands in "10 to 2" position unless they had to react on the stimulus.

During the measurements a following protocol was respected:

- Filling of personal questionnaire (beside others concerning driving skills and experiences).
- Refinement of the mirrors position and angles, so that the driver view full picture projected on the LCDs (but not more).
- Adaptation rounds on the simulator.
- Driving on the highway, while reacting to the red signals by pressing the light horn handler (left and right signals were switched on randomly). After his/her reaction the semaphore changed back to green. The stimulus was shown 40-times (20 for the left mirror and 20 for the right mirror).

In the next picture (Fig.8) it is possible to see the tested driver during the experiment. His/her drive is recorded for further analysis. Besides the above described reaction time, several outputs from the simulated driving are recorded (se for example [3]).

Fig. 8: View on the driver during experiment, recorded using 4 cameras (the blue one is normally used for visual record of outputs from psycho-physiological measures)

6.3 Semaphores - Software implementation

For the purpose of the experiment a new tool had to be developed. In fact it is a virtual semaphore (traffic lights) appearing in each of the mirrors and independently changing its value from green to red. This initial setup was chosen because of the fact that real drivers should naturally notice red signal automatically react in some way. Semaphores do not appear in the scene but they are statically mapped over the 3D image. The traffic lights placed in the virtual world are dynamically changing during driving and therefore they cannot be used (since we need to be sure that the driver always gets the stimulus of the same appearance, size, color and intensity).

The next picture (Fig. 9) shows a schematic diagram of the applications for virtual semaphores. No precise synchronization is needed because the data are mixed together (including time stamps) from all the sources and analyzed offline.

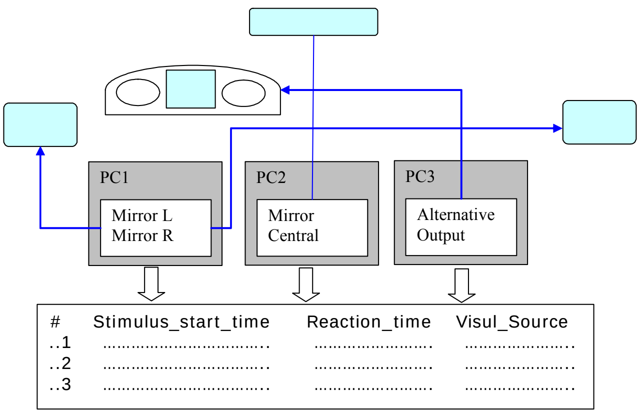

Fig. 9: Semaphore application

6.3 Reaction time - Analysis

The reaction times in both of the mirrors were computed and stored by the "semaphore" application. We did a statistical analysis using *t*-test; first to know whether the reaction time on the left and the right mirror stimulus is really different (Tab.1). In six cases the null hypothesis was rejected, for two it was not possible to reject. So, there is significant difference in majority of cases.

Tab. 1: Reaction time of particular drivers. Highlighted squares denote drivers which exhibited statistically significant difference between reaction time on the stimuli appearing in the left mirror and the right mirror (on α =0.05 and 0.01).

	001		002	
Alpha	0,05	0,01	0,05	0,01
Hypothesis	1	1	1	1
Significance	0,0005	0,0005	0,0003	0,0003
Confidence interval	-983,3704	-983,3704	-1154,8191	-1154,8191
	-298,0296	-298,0296	-376,2809	-376,2809

	003		004	
Alpha	0,05	0,01	0,05	0,01
Hypothesis	1	1	0	0
Significance	0,0081	0,0081	0,123	0,123
Confidence interval	-974,3987	-974,3987	-360,3444	-360,3444
	-155,4013	-155,4013	44,7444	44,7444

	006		007	
Alpha	0,05	0,01	0,05	0,01
Hypothesis	1	1	0	0
Significance	0.0093	0.0093	0.7816	0.7816
Confidence interval	-382.6836	-382.6836	-129.9632	-129.9632
	-57.6164	-57.6164	98.4632	98.4632

	008		009	
Alpha	0,05	0,01	0,05	0,01
Hypothesis	1	1	1	1
Significance	0.0009	0.0009	0.0283	0.0283
Confidence interval	-905.532	-905.532	-740.2676	-740.2676
	-255.268	-255.268	-43.9324	-43.9324

On the other hand in mean value all the probands exhibited higher reaction times when reacting on the stimulus in the right mirror. Also variance is usually higher in "right mirror" reactions. We can explain both of those observations with the fact that the driver has better conditions to continuously observe the left mirror meanwhile the right one is in his/her "discrete" attention.

Tab. 2: Reaction times of particular drivers – mean and variance for left and right mirror.

Driver	mean LEFT	mean RIGHT	var LEFT	var RIGHT
001	1025,00	1665,70	0,1797	0,7354
002	1323,40	2088,95	0,5214	0,6839
003	1218,70	1783,60	0,3144	0,8482
004	1264,00	1421,80	0,2181	0,3907
005	1184,45	1404,60	0,1676	0,3175
006	1057,80	1073,55	0,1915	0,1643
007	952,40	1532,80	0,1104	0,7097
008	1010,20	1402,30	0,2991	0,7086

7 Conclusion

The paper described the software and hardware realization of the system of hybrid mirrors and its incorporation into the system of our driving simulator. We approved need of their implementation for normal driving tasks and experiments with special purpose as well. This solution appeared to be valuable enhancement of our driving simulators. We can say that it successfully competes with fully surrounding projection not only by its lower cost but also by its fidelity (how real the testing drivers feel it). Even though, we have still a lot of space for refinements and enhancements. For example, the original convex mirrors were replaced with planar ones because of the size of our LCDs. The effect of convex mirror image deformation can be restored using specific geometric transformation within the visualization software.

A usefulness of the system of realistic mirrors was illustrated by the real experiment requiring visual information coming from behind. We approved that there is significant difference between driver's reactions on the stimuli appearing in the left and right mirror. The results and experiences from this experiment gave a valuable background for future series of experiments focused on deep investigation in different aspects of driver's field of view and alternative methods for visualization of a situation behind and aside the car.

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