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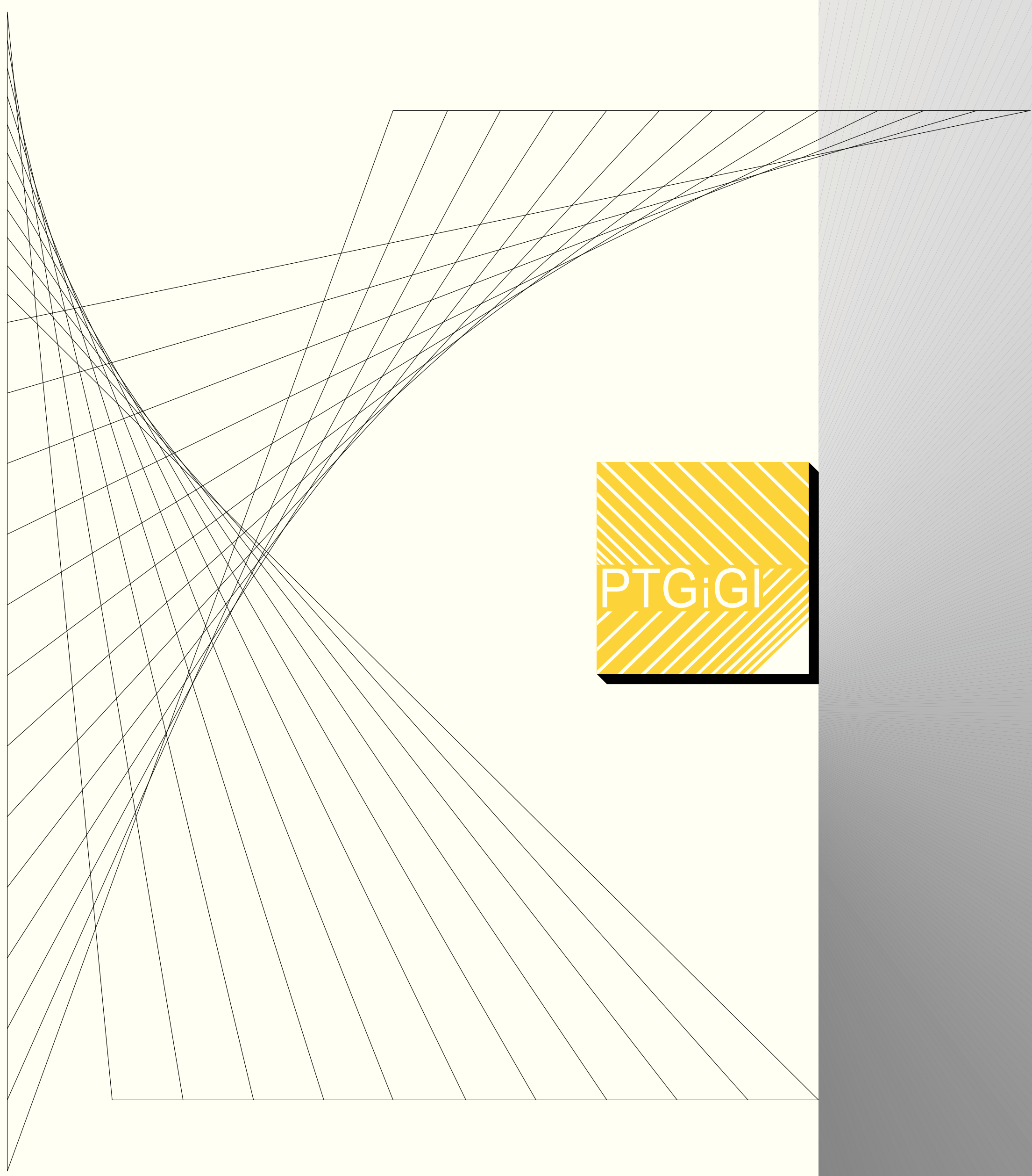

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VISUALIZATION IN TRANSPORTATION – THE EFFECT OF FIELD OF VIEW ON DRIVER'S PERCEPTION OF OBJECTS IN DYNAMIC ROAD ENVIRONMENT SIMULATION

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Abstract. In order to properly study and analyze driver behavior in driving simulators, visualized environment has to be perceived properly by aforementioned driver. Displayed image generated during simulation is a visual representation of virtual road environment and one of properties of this image is field of view. Different values of horizontal and vertical field of view affects whether driver can accept generated image as an image closely reflecting real-world vision. Presented analysis is focused on testing how different horizontal field of view angles impact driver perception, based on series of images.
Increase of horizontal field of view leads to more information of road environment located inside drivers' focused field of view, but can increase image distortion which leads to unrealistic road environment representation in simulation and to perception errors.

Keywords: driving simulation, perception, field of view, computer generated imagery, road environment

Introduction

The last 20 years brought significant developments in the area of computer-generated imagery, allowing it to be applied in various fields of study. Research in the area of driver behavior lead to development of modern driving simulators capable of close to real-world experiences; thus, better understanding of human behavior and perception in various road situations was possible. This paper focuses on analysis of how different values of field of view (FOV) of generated virtual environment influence proper perception. The results not only enhance the scientific knowledge, but also can be used for further research in road perception studies.

Visualization in Transportation

Visualization i.e. generation of series of images in order to convey some kind of visual message to the user is an important tool in transportation studies permitting transportation engineers and researchers to analyze driver behavior in reaction to various visual, auditory, and motion stimuli and to represent various road situations by mathematical models. Hence, visualization is becoming a powerful tool in evaluation of the engineered environment, especially to propose solutions to current road safety problems.

One of the most prominent uses of visualization are various types of simulators, especially driving simulators. These very useful tools, because of focus on perception and the needs of the users, support the process of transport environment design. Driving simulation has a great potential in linking the engineering and human aspects in the processes of planning and designing. Main advantages of simulation research in virtual space are unlimited reproducibility of the simulation and full control of parameters and variables like

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geometry of roads, traffic, and external factors. New integrated simulation systems are still being developed and refined. Virtual reality seems not only possible to be achieved in the near future, but also has a potential to be commonly used as a practical tool for transportation planners conscious about quality of life, safety, and users' needs.

Driver simulators historical background

Driving simulators that are currently used by automobile manufacturers worldwide and created to support research and development of automotive systems were developed relatively recently. In the past, some simulators were rather unsuccessful – either not providing enough visual and sensorial fidelity, lacking the ability to collect important data, or overly complicated for the set research objectives. Recent advancements in driving simulators design were possible because of increasing available computing power, better visual projection systems and better understanding of simulator system architecture. The latter allowed researchers to improve overall harmony between systems' visual, audio, and motion subsystems.

Earliest examples of driving simulators were constructed in the mid-1960s. Among others, notable examples include devices used by the Los Angeles University of California, General Motors, and Volkswagen. These simulators were tailored for their purpose, but not really suitable to support broader vehicle research and development range and transportation studies. Simulators capable of studying driver behavior emerged from the 1970s – amongst them, simulators at the Road and Traffic Research Institute (VTI) in Sweden, at Virginia Polytechnic Institute, at the Institute for Perception (IZF-TNO) in the Netherlands, CRISS at UniRomaTre and the HYSIM Highway Driving Simulator at Federal Highway Administration in the USA. Current generation driving simulators that started to show up in the 1980s included instruments at Daimler Benz, improved VTI simulator, and driving simulator at Dynamic Research, Inc. (DRI). These simulators, capable of efficient support of driver behavior studies, were followed by development of "world class" National Advanced Driving Simulator sponsored by the United States National Highway Traffic Safety Administration in the late 1990s. More recently, major car manufacturers developed even more advanced simulators capable of high fidelity image generation, motion capabilities, and responsive steering wheel controls. Their main purpose is to support of vehicle research and development efforts expanded to include study of human-machine interfaces (HMI), instrumental trans-communication, and evaluation of a wide range of driver behavior issues.

Importance of driving simulation in transportation studies

Because of its focus on perception and users' needs and potential to link the engineering and human aspects in planning and designing processes driving simulators are very useful tools supporting the process of transport environment design.

Analysis of strengths and weaknesses, opportunities and threats (SWOT) application in integrated systems of driving simulators, carried out on the basis of existing studies indicate that advanced visualization is a promising research tool for interdisciplinary studies in transport.

Strengths:

1. Repeatability of each simulation geometry,
2. Ability to simulate and fully control every road situation, design, and event, including environmental, traffic, and external factors,
3. Measurability of traffic parameters with high resolution (speed, acceleration, etc.),
4. Monitoring of the driver in the real time.

Weaknesses:

1. Lack of full comparability of qualitative assessments and quantitative measure perception reaction.

Opportunities:

1. Multidisciplinary approach to drivers' behavior.
2. It can become standard for assessment studies.

Threats:

1. Output requiring special arrangements.
2. Results may be biased

Advanced modern simulators allow for obtaining a realistic driving experience in the laboratory. The equipment usually includes high quality hydraulic devices integrated with a simulated computer-generated images that evoke the impression of a full vehicle dynamics (vibrations from the road surface, acceleration and delays, the centrifugal force, etc.). The visual system is usually coupled with computer graphics, which permit for collection of high frequency images with minimal delays.

The current applications of driving simulators include a wide range of studies: infrastructure research, a system of interactions "road-car-driver", design of roads, tunnels, and bridges, vehicle control, testing of In-Vehicle Information Systems (IVIS) devices as well as evaluation of ergonomics, psychological and behavioral aspects, biomedical and pathological analysis, the effect of alcohol and drugs on driver's perception, behavior and reactions of drivers in challenging road conditions, behavior of drivers with disabilities, and many more.

Optic flow and field of view

Driving simulators based on virtual reality have special requirements for displays used in their setup. Optic flow, i.e. pattern of apparent motion of objects generated in the modeled 3D environment should be the closest to one found in real driving experience. Anticipation of approaching objects in road view using optic flow can be applied in several driving tasks, like steering around dynamic and static objects present or appearing in proximity of the road and to obtain heading information about road curvature. Study of optic flow is often combined with tracking of driver's eye movement. Former studies show that usual focus point lies near the point where the road meets the horizon. While for the driver this point appears stationary, the optic flow expands towards vehicle. While approaching road curves, focus point shifts to location tangent to the curve, letting the driver to approximate yet unseen incoming road curvature. That focus point moves as the driver traverses the curve. Using the focus point, the driver may analyze changing patterns in optic flow while assessing road situation.

One of the most important elements of a driving simulator is the visual system, which advanced from cathode-ray tube (CRT) and film techniques to computer graphics imagery systems. Nowadays, these system depend on real-time generated visualisation of driver's view, either projected or displayed on high resolution screens. Display delay is minimized to ensure responsiveness of the visualization to driver controls, which necessitates the use of a computing unit of sizeable processing power (Four core processor, dedicated workstation class graphics card).

In virtual driving simulators, optic flow is different form that observed in real world. Difficulty of optic flow implementation lies in large horizontal width of human vision, which cannot be directly displayed on computer monitors, even on large screens used in driving simulators. For that reason, simulators compress horizontal view of real world (about 180^o degrees, including peripheral vision) to a field of view of a virtual scene, usually wider than real world equivalent, i.e. if screens compose of 180° coverage, applied FOV can be 220° or even wider. This geometric field of view (GFOV) depends on simulator display setup (ranging from small computer monitors to large, wide angle projection screens) and needs to be set individually. Additionally, in synthetic driving environments, where no motion stimuli are involved, GFOV can be modified according to simulated vehicle velocity, thus modifying perceived optic flow, usually applied by human brain facing probable hazard. The study published in 2007 by Ronald R. Mourant and co-workers from Northeastern University of Boston [6] demonstrated that increase in simulator GFOV made drivers believe to be travelling at speed higher than anticipated. Increasing optic flow of road by adding more objects in the proximity of road produces the same effect of increased perceived velocity.

Field of view in computer generated imagery

In virtual driving simulators, FOV can be generated with different parameters including horizontal and vertical FOV variations and screen resolution ratio; these parameters can be calculated one from another using equation (1) using values measured according to Fig. 1.

Scene view, generated from the same point of origin, can be perceived differently depending on these parameters. Figures 2, 3 and 4 show how different horizontal field of view (HFOV) looks on single and triple screen configurations using 16:9 display ratio. Presented configurations are shown in standard display, where vertical FOV (VFOV) is changed according to HFOV, anamorphic, where vertical display resolution is constant, and anamorphic, where VFOV is constant:

$$r = \frac{y}{x} = \frac{\tan\left(\frac{VFOV}{2}\right)}{\tan\left(\frac{HFOV}{2}\right)}. \tag{1}$$

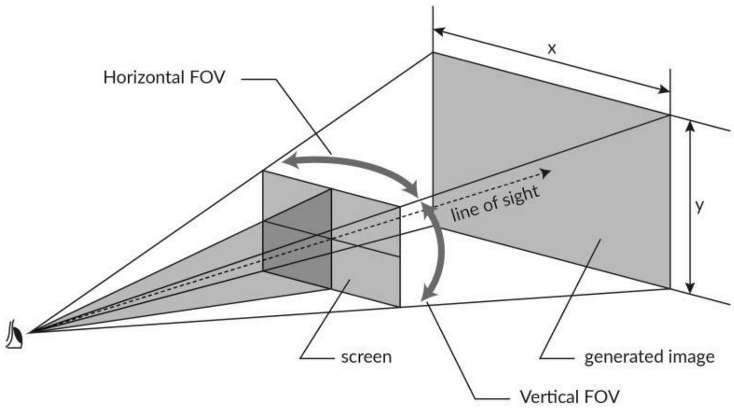

Figure 1: Parameters of field of view in computer generated imagery

Increasing both HFOV and VFOV proportionally with fixed display resolution creates an effect of increasing distance between driver and road, resulting in better orientation in virtual environment, at cost of worse road perception. Objects in FOV are perceived as proportional.

Vertical resolution in anamorphic projection of virtual environment in Fig. 4. is set in this example on 1000 pixels. Horizontal resolution is calculated from proportional equation, starting at 30° with width of 1000 px, then increasing by 500 px for each increase of 15°, which results in changing VFOV. Projected image is then rescaled on either one or three 16:9 ratio displays. Objects in wider horizontal FOV look narrower, along with visible slant of vertical surfaces.

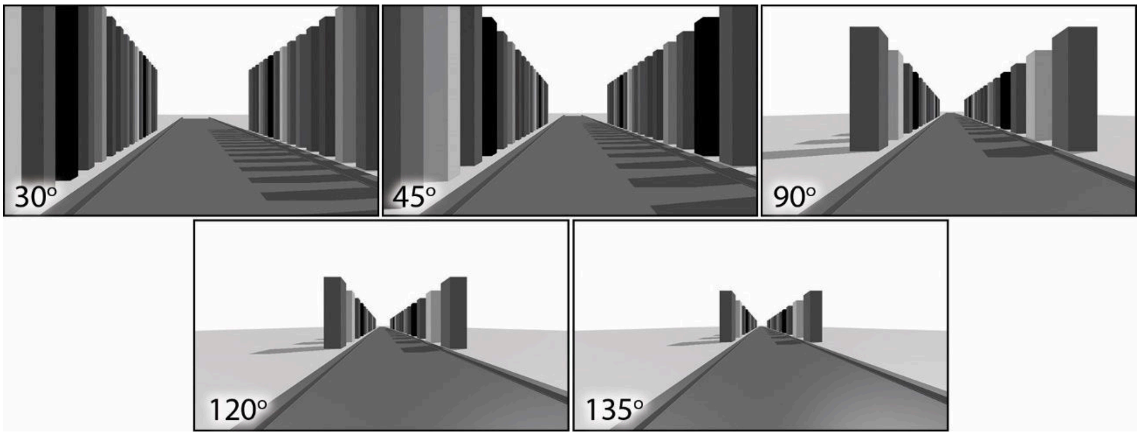

Figure 2: Proportional field of view ratios on 16:9 display. Set FOV, from top-left, to bottom-right: 30°, 45°, 90°, 120°, and 135°

Using constant VFOV angle (as in Fig. 4) leads to another anamorphic projection of virtual environment, resulting in visualization that could be compared to a corridor. With vertical resolution and fixed FOV of images, horizontal resolution is calculated from equation 1, after which images are rescaled to fit either one or three 16:9 displays.

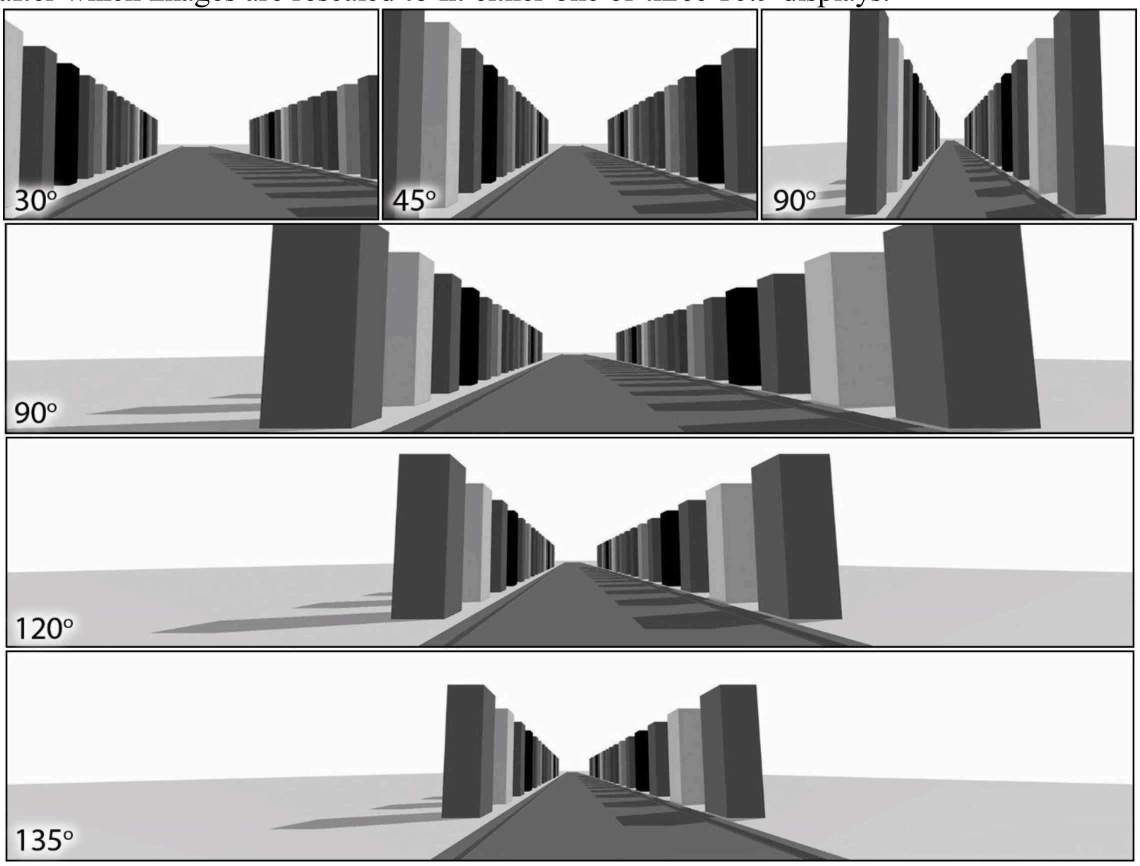

Figure 3: Anamorphic field of view with constant vertical resolution. Set HFOV, from top-left, to bottom-right, on single 16:9 display: 30°, 45°, 90°; on three 16:9 displays: 90°, 120°, 135°

In computer-generated imagery it is suggested to use field of view with constant VFOV, as it corresponds quite well to natural human vision if appropriate display width configuration is used. Anamorphic field of view with constant vertical resolution could lead to distortion of image, leading to perception misconception, and proportional view, although natural, without increase of screen height and width could lead to distance estimation errors and roadside environment elements appearing too small to be properly distinguished. Increase of display area, although beneficial for research, may also lead to unjustifiably high cost of equipment needed to generate image.

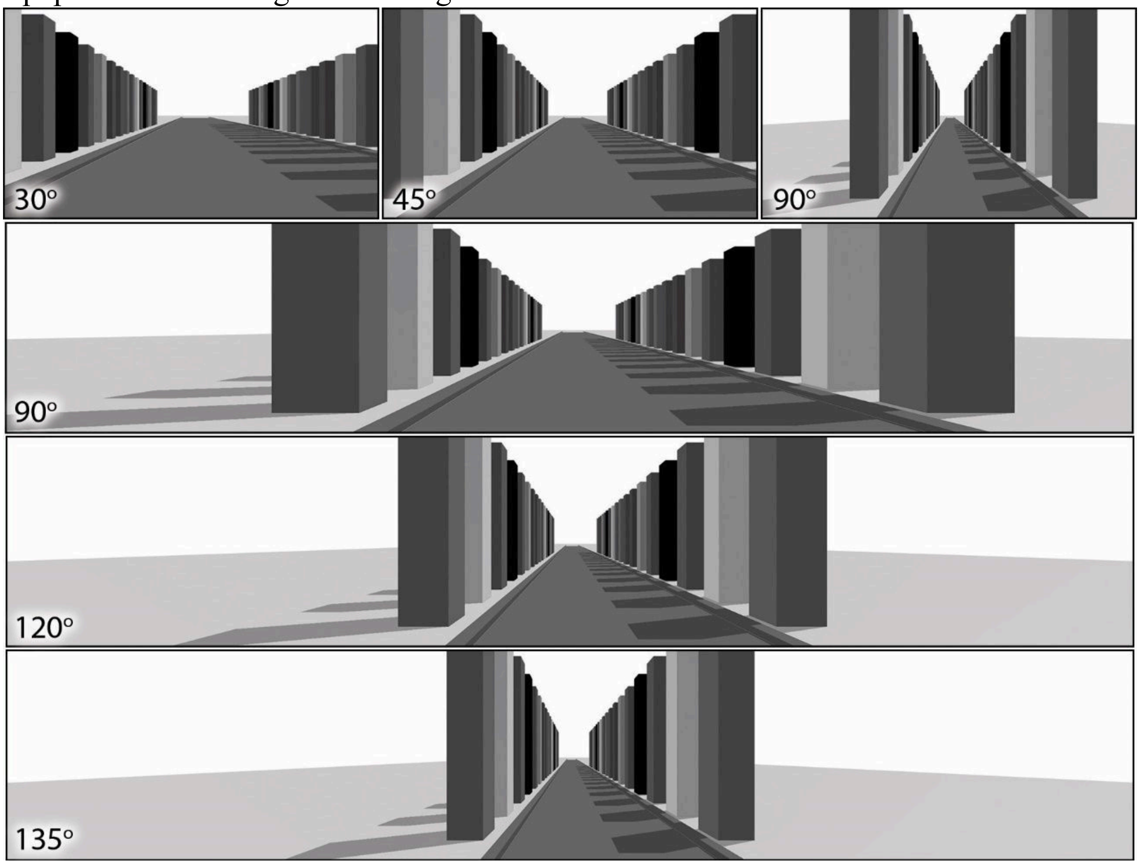

Figure 4: Anamorphic field of view with constant VFOV. Set HFOV, from top-left, to bottom-right, on single 16:9 display: 30°, 45°, 90°; on three 16:9 displays: 90°, 120°, 135°

Field of view and driver's focus depending on driving simulator configuration

Considering how a set FOV affects the amount of virtual environment displayed to driver, Figures 6.-9. demonstrate how a driver perceives simulated road environment in different simulator configurations. On the left side of each figure, position of driver's head is shown in relation to the display, darker cone represents focused vision, lighter – peripheral field of vision. On the right side are images representing displays generated using anamorphic projection with constant vertical FOV. Numbers on images correspond to the used HFOV, and darker circle represents driver's focused field of view (FFOV), i.e. amount of virtual environment the driver can distinguish without eye movement and head rotation, which in the following cases is set at 15 degrees, which is close to value considered border between focused and peripheral vision, as shown by J. Milton Johnson already in his work from 1892 [10].

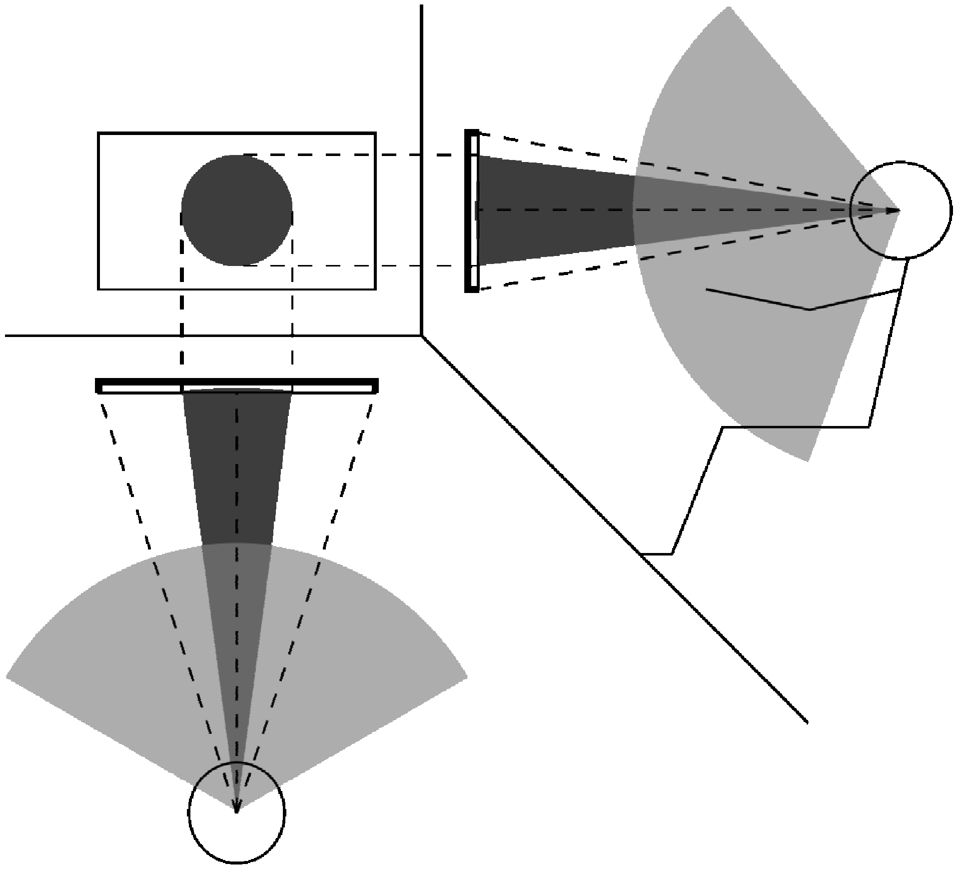

Figure 5: Focused field of view in computer generated imagery. Dark areas represent FFOV, lighter represent peripheral view area

VFOV in Figures 6-9 and Tables 1-4 are provided as the amount of visual angle occupying the vertical size of particular used display. The values are calculated based on display size and distance between display and person looking at the screen, using trigonometric functions.

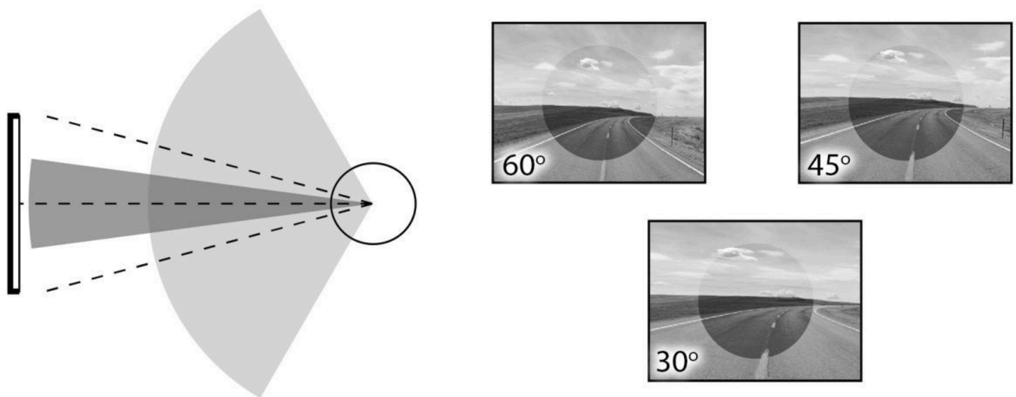

Figure 6: FFOV for single 19 inch, 4:3 display ratio monitor, driver distance from screen: 0.8 m; top-down view of display configuration, and generated images for 60°, 45° and 30° HFOV

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Table 1: Change in area of generated image visible in FFOV for single 19 inch monitor, 4:3 display ratio (source: own study)

VFOV	HFOV	Percentage of area in FFOV in relation to lowest specified HFOV
20.51°	30°	100.00%
20.51°	45°	154.84%
20.51°	60°	215.48%

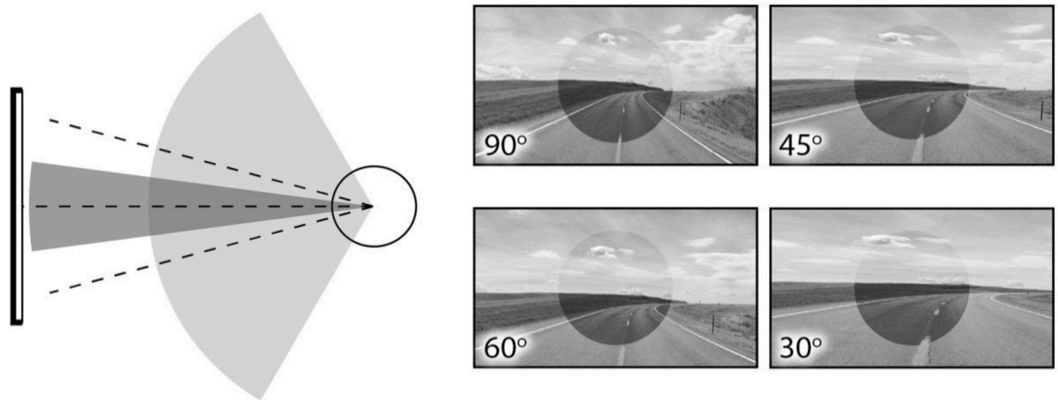

Figure 7: FFOV for single 24 inch, 16:9 display ratio monitor, driver distance from screen: 0.8 m; top-down view of display configuration, and generated images for 90°, 60°, 45° and 30° HFOV

Table 2: Change in area of generated image visible in focused field of view for single 24 inch monitor with 16:9 display ratio (own study)

VFOV	HFOV	Percentage of area in FFOV in relation to lowest specified HFOV
21.16°	30°	100.00%
21.16°	45°	155.05%
21.16°	60°	216.06%
21.16°	90°	373.85%

Single display simulator configurations (Figures 6 and 7) used in most entry-class driving simulators capable of driver perception and cognition research and testing exclude wide peripheral vision. They are adequate for testing of roadside infrastructure and pavement markings recognition and perception. Cost of simulator, based on this configuration is relatively low, leading to its common application in non-demanding research studies.

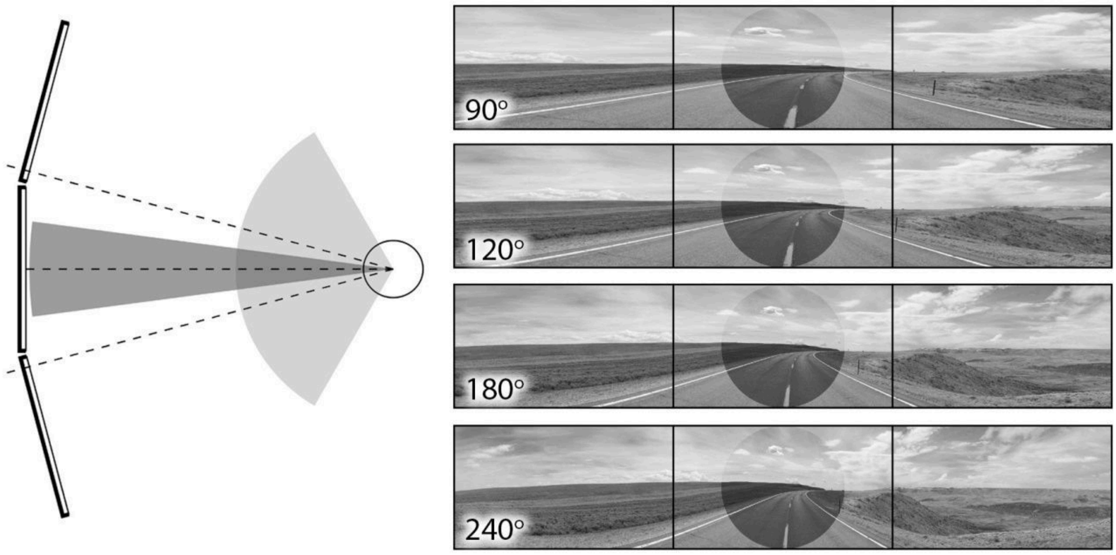

Figure 8: Focused FOV for three 24 inch monitors, each at 16:9 display ratio, driver distance from screen: 2 m; top-down view of display configuration, and generated images for 90°, 120°, 180°, and 240° HFOV

Table 3: Change in area of generated image visible in focused field of view for three 24 inch monitors, each at 16:9 display ratio (own study)

VFOV	HFOV	Percentage of area in FFOV in relation to lowest specified HFOV
8.55°	90°	100.00%
8.55°	120°	135.82%
8.55°	180°	215.38%
8.55°	240°	313.19%

Mid-class driving simulator configuration with three displays (Fig. 8) presents wider view on virtual environment, allowing research of not only perception, but also drivers' reaction on events and objects outside of the focus vision.

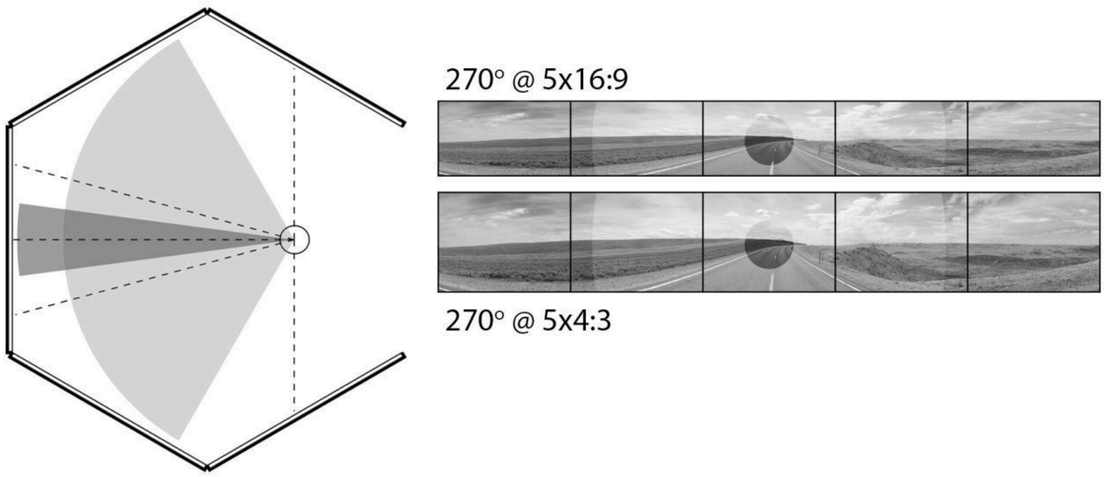

Figure 9: FFOV for five 32 inch 16:9 ratio displays or five 36 inch 4:3 ratio displays; driver distance from screen: approx. 2 m (source: own study)

Table 4:

Display ratio	VFOV	HFOV	Percentage of area in FFOV in relation to 4:3 display ratio configuration
4:3	13.90°	270°	100.00%
16:9	11.37°	270°	102.85%

Configuration of high-class driving simulator, presented in Figure 8, allows complex research of driver behavior in road environment involving full 360° vision, with rear vision displayed on an additional screen located in place of the rear view mirror. Additional sound system could be used to indicate appearance of vehicles and other entities outside of FFOV, which can be used for in-depth driver attention research with viso-motoric response time test.

Tables 1-4 show how a change of HFOV affects computer-generated image area inside driver's FFOV for a single display. VFOV was calculated to correspond to the size of display and its distance from driver. With increase in HFOV, an increase in the area inside FFOV was measured. However, it has to be taken into account that while theoretically more can be seen, due to accumulation of onscreen objects it depends on display pixel density whether details of virtual environment are displayed correctly.

Conclusions

The on-going advancements in computer generated visualization leads to the wider use of driving simulators in perceptual studies for safer behavior, in which virtual road environment is closer to the real road view observed while driving. The proper evaluation of virtual field of view is necessary in each case in order to rich the best perceptual condition in simulated environment.

In simple studies on road safety regarding drivers' behavior, highly advanced driving simulators are not critical, especially while simple laboratories are developed and used without high costs today. An entry-level single screen simulator were found to be sufficient to test driver perception of road situation and at the low costs. Advanced simulation could prove useful in studies involving various types of reactions, both psychological and viso-motoric.

This work has shown that field of view in driving simulators has a very significant effect on the quality of virtual image of the road environment. The proper field of view should be carefully chosen based on parameters like display size, separately vertical and horizontal, and viewer distance from the display. Horizontal field of view, corresponding to the angular space occupied by the simulator's display, should be tested and selected to better represent natural environment. In simulations with different objective than realistic perception of road environment, the horizontal field of view may be increased, to maximize number of objects, in a way that it fit in focused field of vision (from 2.85% to 273.85% increase), depending on the simulator configuration and suspected results. This study presented that in case of simulation, more does not always means better.

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WIZUALIZACJA W TRANSPORCIE – WPŁYW POLA WIDZENIA NA POSTRZEGANIE OBIEKTÓW PRZEZ KIEROWCĘ PODCZAS DYNAMICZNEJ SYMULACJI OTOCZENIA DROGI

W celu poprawnych badań i analiz zachowań kierowcy w symulatorach jazdy, należy zapewnić odpowiedni odbiór wirtualnego środowiska przez kierowcę. Wyświetlany obraz generowany podczas symulacji reprezentuje wirtualne otoczenie drogi, a jedną z właściwości tego obrazu jest pole widzenia. Dopasowanie wartości pionowego i poziomego pola widzenia warunkuje akceptowalność obrazu przez kierowcę, jako odpowiadającego rzeczywistości. Przeprowadzona analiza skupia się na wpływie różnych wartości poziomego pola widzenia na postrzeganie kierowcy, opierając się na serii obrazów.