Semi-Cave as an Example of Multimedia Dedicated to Study the Impact of Audiovisual Environment on Human Psychophysiology

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Abstract: Cave (Cave Automatic Virtual Environment) is an example of a multimedia installation that allows perceiving virtual reality (VR) in its best form. The aim of the work is to present a cave solution defined for specific applications. The low-budget concept called SEMI-CAVE has been proposed in order to study the impact of audiovisual environment on human psychophysiology. This approach enables to create virtual indoor or outdoor workplaces, with reference to many aspects of human psychophysiology like wellbeing, fatigue, mood and alertness. Virtual environment allows taking into account any visual factor or element important in real workplaces. One of the rarely considered is glare, which is also intended in the research. Overview of known and applied VR solutions and analysis of their properties allowed selecting a solution adjusted to specific expectations and requirements. On the other hand, according to VR taxonomy, we have proposed solution which can be treated as the new form of VR realization – unusual combination of well-known CAVE and CAVE2 designs. The first stage (closed part) of project realization is presented in the paper.

1 INTRODUCTION

1.1 Motivation

The virtual reality (VR) has become one of the most interesting and, at the same time, the most important achievements of computer science in recent years. The VR technique is most often used in computer games and various forms of entertainment. However, many areas of science can be shown, where the use of VR techniques not only speeds up the study, but also facilitates them or sometimes simply allows conducting the research.

The proposed realization – SEMI-CAVE – is an example of multimedia laboratory of modeling lighting scene, images and sounds. It is one of the laboratories which were built in the scope of project Tech-Safe-Bio, which was realized in recent years in Central Institute for Labour Protection - National Research Institute (CIOP-PIB). The objective of the Tech-Safe-Bio project was to construct the infrastructure and to equip the scientific laboratories group functioning in the structure of CIOP-PIB with modern research equipment. This action was necessary to create the potential for high quality advanced research in line with strategic national and European research programmes (TECH-SAFE-BIO, 2015). The new building with the wide range of bot, L., DeFanti, T., Brown, M., Jeong, B., Jagodic, Centre for Research and Development on Work Processes and Safety Engineering. The state-of-the-art laboratories are adjusted to conduct interdisciplinary research focused on protection of health and safety of workers among others in the scope of: impact of physical environment on workers and design of workplaces using virtual reality techniques and computer simulations which are attached to research area planned in SEMI-CAVE laboratory.

1.2 The Aim of the Article

The main aim of this paper is to present the realization of multimedia SEMI-CAVE laboratory as

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a specific VR installation developed for the study the impact of audiovisual environment on human psychophysiology in the interdisciplinary research. The project involves the combination of properties of known solutions type CAVE and CAVE2, not previously used in such a scale.

2 VIRTUAL REALITY – THE SURVEY OF DIFFERENT REALIZATIONS

The first virtual environment as a CAVE (Cave Automated Virtual Environment) prototype was built in 1991 (Cruz-Neira, et al., 1992). The number of publications concerning only different technical solutions of VR has exceeded 20 per year for many years (Kim, et al., 2013). Many review articles have been published (Kim, et al., 2013, Zhou, et al., 2009, Muhanna, 2015), according to which few basic categories of technical solutions for VR could be distinguished.

2.1 CAVE

The first CAVE installation displays images in rear-projection system on three walls, ceiling and floor. It was built as a cube of 2.1 m side length. But in the reality the whole installation occupied much more space, because of outer projectors and support structure (Cruz-Neira, et al., 1992). Later on six walls cube appeared but also realization of two walls (Nichols and Petel, 2002), four walls (CAVE Automatic) and five walls (Sony 4K) are known. Contemporary, the most expanded solution included projection on 15 side walls, floor and ceiling (DeFanti, et al., 2009). Different image resolutions of the range from 1024x768 (Juarez, et al., 2010) to 6000x4096 pixels were applied for single wall image (CAVE Automatic). There are also CAVE solutions based on sphere (Fernandes, et al., 2003), or mixed solutions where the sphere is inside the cube (Mazikowski and Lebiedź, 2014). Apart rear-projection the inside CAVE projection on the walls is also used (Jacobson and Lewis, 2005). It gives opportunity to get CAVE of much more space at the comparable dimensions of all installation.

The main problem of all CAVE solutions is complicated graphical representation. The special attention is paid on image stitching (Sajadi and Majumder, 2011) and quality dependency on angle of observation and observer's position (CAVE VR, 2014).

The most important applications of big CAVE installations are vehicle simulators (flight, car, etc.) which allow almost completely limit the risk of accident during the tests or training (Muhanna, 2015). CAVE is also implemented in contents presentations for advertising and marketing purposes (Sony 4K), entertainment and education. It is also worth mentioning about medical applications, patients immersed in virtual reality can, for example, fight phobias (Emmelkamp, 2004).

In the wrong designed CAVE installations the user could feel strong and long lasted vision disorders. On the other hand, even in properly designed CAVE, people could have sense of isolation, disorientation, frustration, or even panic (Nichols and Petel, 2002).

2.2 CAVE2

According to technological development the projectors were exchanged to LCD monitors. This solution (CAVE2) gives both possibility of considerable reduction of installation space and achievement of considerable higher image resolution (Febretti, 2013). But the visibility of small space gaps between screens constitute the main disadvantage of that solution. It could make difficult immersion into virtual reality (Leigh, et al., 2007, Krumbholz, et al., 2005), especially in small installation.

The chosen CAVE2 solutions make easy the leading of training (Leigh, et al., 2007) and monitor the processes and events (Lambda Table) (Leigh, et al., 2007, Krumbholz, et al., 2005). The extension of multimodal interaction could make these solutions efficient for medical applications (3D Visualization) and interdisciplinary applications, which use computer technologies (Febretti, 2013).

2.3 Binocular Head based VR

The lowest space virtual reality is technical solution based on helmet or head mounted display (HMD) (Melzer and Moffitt, 1997). It is VR realization in a form of local view which is available individually for each participant thanks to special glasses which displays images for left and right eye separately. There are several products (HTC Vive, Oculus Rift, PlayStation VR), commercial available of that solution. These devices are equipped in additional sensors for head position identification (Muhanna, 2015, Spec Comparison). The cheapest solution, especially popular in recent years, is smartphone usage as a display of binoculars (Review: VR BOX

II, Samsung: Gear VR). This is most commonly used for computer games.

The basic advantage of HMD is fully independence from complicated installation construction. HMD could be used in any place and only needs the computer with adequate software. In comparison to CAVE it is huge costs reduction. On the other hand this solution requires additional equipment (e.g. gloves) and doesn't allow to fully sensory and motion identification with VR environment. Additional problem is related with motion sickness, related to labyrinth dysfunction (Davis, et al., 2015).

In the beginning it seemed that HMD would displace CAVE solutions for financial reason. But it hasn't happened. Nevertheless HMD solutions are currently often used. Among professional applications the most important are education and training (especially military) (Muhanna, 2015, Castaneda and Pacampara, 2015), and robot control (Kot and Novák, 2014).

3 EXPECTATIONS FROM VIRTUAL REALITY RELATED TO PLANNED STUDIES ON THE IMPACT OF AUDIOVISUAL ENVIRONMENT ON HUMAN PSYCHOPHYSIOLOGY

Having the spectrum of virtual reality technical solutions as well as related costs of theirs realization we had to consider the best solution to achieve the main goal – virtual reality dedicated to study the impact of audiovisual environment on human psychophysiology. Virtual reality and created this way virtual environment which allows users performing different tasks in a specific audiovisual environment that he or she is familiar with or not. The approach which enables us to create sounds and visualization of different indoor or outdoor places, workstations, interiors of different colors and furnishings etc. That way we can create the light scenes, images and related sounds that could influence the human psychophysiology with reference to: wellbeing, comfort, fatigue, relax, mood and alertness. Taking into account the great importance of spectral light distribution on human circadian rhythm, fatigue, mood, mental performance and efficiency the virtual environment will be used for many studies concerning those aspects. It should be possible to adjust visual environment to the users' needs, preferences and health. We expected to create the virtual environment as one of new method for visual environment forming and study its influence on people. A change of real visual environment to carry out research on its influence on human is not possible or very expensive. Creating in virtual environment an apparent visual environment of real places allows avoid that.

One of the planned applications of virtual environment is creation of unique laboratory for extended glare investigation. Virtual reality should enable to put inside the programmable glare sources and create different background luminance or the images of real working environment. The studies concerning objective and subjective glare evaluation with participation of healthy people or people with different visual impairments let us to develop methods of glare evaluation and verify actual glare indexes.

Our virtual reality could be possibly great tool for managers / employers that want to prepare workplaces for their subordinates. With a help of virtual environment we can now not only look at visualization on the screen, but as well "enter" inside the workplace we want to create. Or even invite the team to see and consult our idea first in VR – before we prepare the finished project.

Virtual reality will be used to create an exact environment in order to test different abilities that users possess such as: reaction time, creativity, ability to logical thinking etc. While they complete multiple tasks inside of virtual environment, their execution time, approach and abilities of problem solving can be registered and marked. Based on that information we can distinguish properties of task and individual behaviour.

The installation of virtual environment should be equipped with simple and intuitive mechanism of control. Simple control panel that allows staff to change scene quickly, to view, for example, panoramic pictures. In the future such mechanism could be further enhanced and upgraded in order to allow better and easier control over shown content while also increasing interaction level and immersion of participant inside of room. This way organization of hardware and application should be today open enough that it cannot block developments in the future.

Virtual reality is not just images. Sound information is also very important. The project should include a good sound system that correlates acoustic impressions with visual impressions and ensures consistent interpretation of the proper spatial directions in both cases. At the same time, it is worth noting that regardless of spatial sound system, the project must include the possibility of simple communication between staff and participants of experiments.

Safety of participants should be guaranteed by monitoring cameras. Continuous display of what is happening inside the room allows staff to react within seconds on any unexpected or dangerous events.

4 MEETING EXPECTATIONS – ANALYSIS AND SOLUTION SELECTION

The expectations and plans related to virtual reality presented in paragraph 3 were the starting point to choose the best category of installation in a limited financial budget. Firstly the solutions which use binocular head based VR were rejected, because they don't give the opportunity of teamwork with eventual using the real working equipment (like office accessories) in VR room. At the same time actually there is no possibility to obtain very high level of luminance using those technical solutions of VR. This way it would not give us a chance to do studies on glare in that virtual environment, what was one of our expectations from VR. It made us to choose CAVE category of virtual environment.

One of the arguments in favor for choosing the type of virtual reality was the need of relatively big dimensions of the room (VR space). The cube of wall size length of 2.5 m to 3m like in a CAVE with rear-projection – was dedicated for one person staying inside. Enlargement of the VR room leads to increasing the size of all solution, even if special projectors of short focal length would be used. On the other hand the glass floor would increase the costs significantly without possibility to put any test stand on it.

In result of considerations of different solutions the decision of realization the CAVE environment with direct – inside projection was made. It is related to compromise between big space inside for experiments and lack of image on floor and ceiling. That way we worked out the concept of SEMI-CAVE, with display images on four walls. This solution has got also disadvantages. The main was the necessity of increasing the number of projectors, what is related to geometrical problems with stitching images. It was assumed that our virtual reality will be realized in a room of dimensions: 8.6m x 4.3m and the minimum height of image will be 2.8m. Such room sizes seem to be a reasonable compromise between the simulations of the working environment and the immersion benefits of the virtual environment.

An independent analysis was carried out for possibility of glare simulation. Known solutions (Clear, 2012) give the opportunity to study only

Table 1: The comparison of different VR realizations and our proposition (SEMI-CAVE).

	CAVE rare projection	CAVE inside (front) projection	CAVE2 LCD/monitors	HMD	SEMI-CAVE
VR space (room size)	Very small	Any size (cost)	Any size (cost)	Any size	Any size (cost)
The whole installation size	Very large	Small (like VR space)	Medium (a little bigger than VR space)	Depend on installation	Small (like VR space)
Mixed realisation (e.g. VR background + real furniture)	-	+ +	+ +	- -	+ +
Team working	-	+	+	- - (only in VR)	+
Feeling of participant, disorders	- -	-	-	- -	-
Possibility of development, (expansion)	NO	YES	Difficult	NO	YES
Glare simulation	NO	NO	YES (special equipment)	NO	YES
Cost	Very high	Medium	High	Low	Medium

single glare source influence on human perception. And don't give the possibility to take into account the luminous environment in any working environment. To make it possible in virtual reality it is necessary to see the image consistent with the image of working environment and at the same time the glare sources of real luminance (at the level of million cd/m^2) should appear. This solution is not possible in a standard CAVE and HMD. We assumed to introduce to the room new semi-transparent wall to display on it the image from projector. At the same time beyond that wall the special designed programmable panel with LED sources of very high luminance will be placed. As a result the observer inside the CAVE would experience environment similar to the real working environment (image form projectors) and glare (LEDs light beam through the semi-transparent wall). The analysis of available semi-transparent screens and LEDs showed the possibility of correct realization of that solution. Unfortunately because of the high costs of that solution the realization of that idea will be carried out at the next stage. It is worth to notice that proposed solution combines features of CAVE and CAVE2.

The comparison of different VR realizations and set of basic properties of our proposition (SEMI-CAVE is presented in Table 1.

5 SEMI-CAVE – REALIZATION

In the implementation the following assumptions for the SEMI-CAVE system were adopted:

- Room 8.6m x 4.3m x 6m, with internal projection.
- Minimum image height: 2.8m.
- Additional room (control room) adjoining the wall.
- Projection: providing a shadow-free approach, assuming that participant with a height of 1.7m can be in minimal distance of 1m to the image (to all four walls of the room).

5.1 Installation and Projection

The assembly of all components was realized using a truss suspended to the ceiling and stabilized to the walls of the room. The truss design was based on modular elements that have been chosen to ensure the load capacity and stability of the structure and deflection resistance for the whole of the planned installation. The truss has been placed at a height of 3.8m. Projectors, sound system, lighting fixtures and intercom with voice communication system to server room have been installed on the truss (Figure 1).

Six projectors with the following parameters were selected for displaying images: brightness at level of 4000 lm ANSI, WUXGA resolution (1920x1200), LCOS matrix. The LCOS matrix minimizes image pixelization. The projector has

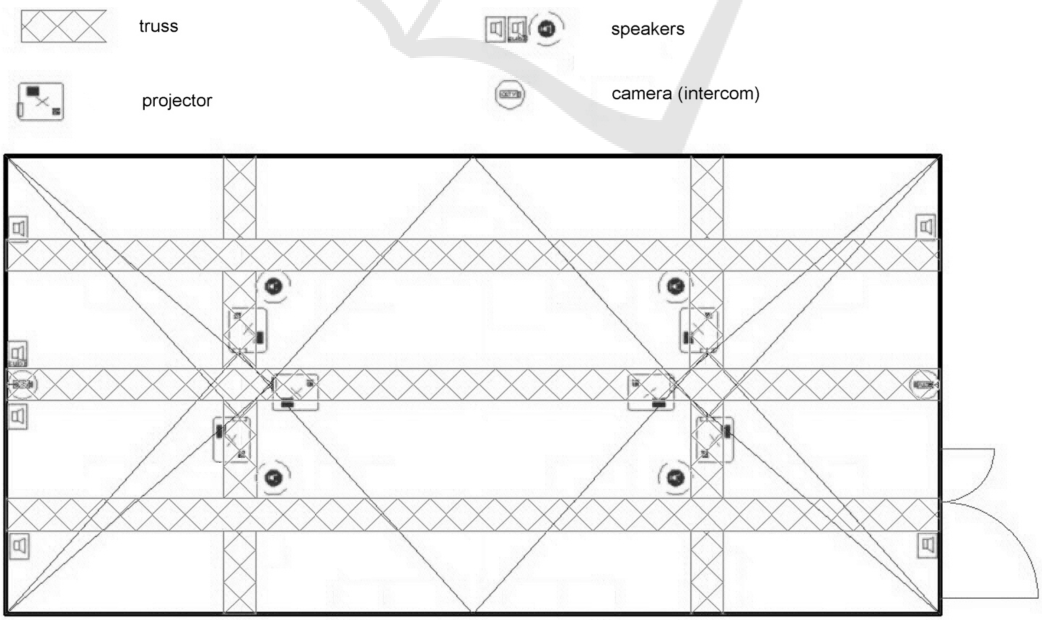

Figure 1: Arrangement of projectors in the room.

built-in edge blending mechanism. Short throw optics with Lens Shift and Keystone Correction in two directions made it possible to obtain the expected shadow free area of work (Figure 2). The transmission of the image from the computer in the control room was realized in the HDMI technology. The location of the projectors at a distance of 2.45m from the wall provided a 4.3m x 2.8m image. One projector for shorter walls and two for longer walls were installed.

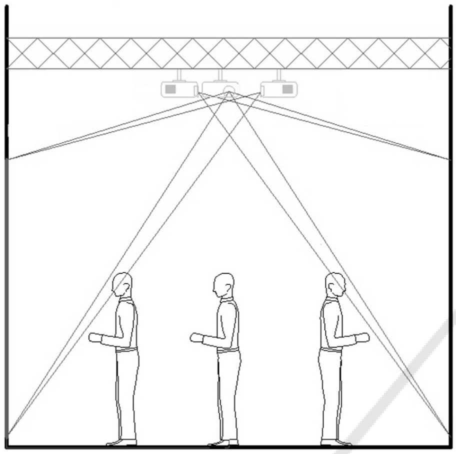

Figure 2: Arrangement of projectors against walls - providing the right work area.

The audio system was implemented in 5.1 surround sound. Speakers were chosen to ensure proper listening in the VR room. The HiFi amplifier and other control elements were placed in the control room.

There are two subsystems complementing the installation. The voice communication subsystem (intercom) based on four ball speakers arranged to provide a uniform level of sound and the visual monitoring subsystem based on two cameras displaying a real-time image on a 22"monitor in a control room with the possibility of data recording.

5.2 Computer System

The SEMI-CAVE computer system consists of two computers connected by standard 1Gb Ethernet network. Operation carried out by computers was distributed functionally, therefore, only synchronization tasks are realized via Ethernet. The first computer generates images and displays them over the projectors. It is a computer based on 2 Intel Xeon processors, with 64GB RAM and SSD Hard Drive.

The heart of the computer are three high performance graphics cards GTX980 4GB Strix OC connected via SLIs bridge. Each card supports two images (two projectors). GTX980 cards have been selected for configuration, although they are not supported by nvidia's standard multi-monitor projection software (Mosaic). This means that, using them, it is not possible to display and synchronize 6 images simultaneously. So, this solution does not support our project.

Nvidia is forcing customers to purchase significantly more expensive graphics cards that are not more efficient but are compatible with the corresponding software standard. We had to solve this problem. A special shader driver has been

Figure 3: Alley from the Warsaw Saski Garden in SEMI-CAVE. View of the entire laboratory.

developed that allows displaying and synchronizing images. Our driver allows effectively displaying and synchronizing 6 images from GTX980 cards. This solution made it possible to make the full use of the equipment in SEMI-CAVE laboratory. The purpose of the second computer is to support the audio subsystem and to manage additional functions.

Figure 4: Alley from the Warsaw Saski Garden in SEMI-CAVE. The garden lamp in the corner of the laboratory.

6 SUMMARY

The project of the multimedia SEMI-CAVE Laboratory required an analysis of needs on the one hand, and implementation possibilities on the other. Hence, a review of the state-of-the-art solutions was essential to make proper decisions. For the purpose of this paper, it has been supplemented by contemporary publications. The results of the analysis of existing solutions, spatial possibilities and the budget indicated the necessity of developing a low-budget concept called SEMI-CAVE. The first stage of SEMI-CAVE installation has been built and despite some limitations (image height max 2.8 m, no ceiling and floor display) it meets our expectations. The proposed solution is an unusual combination of well-known CAVE and CAVE2 designs – never before practiced together in such a scale.

The laboratory was initially launched in the end of 2015. The first work involved calibration and geometry support. As part of the experiment, a method of acquiring images for viewing with the use of photographic equipment. Obtained images and impressions of viewers have confirmed the correctness of the concept (Figures 3 and 4) in terms of image display. At the same time the initial experiments confirmed sufficient immersion into virtual reality.

The new display subsystem supporting the used graphics cards has been developed. The used projectors combine the images in edge blending technology. This solution gives excellent results at the initial stage of display. However, to provide full control over the geometry of the merged images, the new blending subsystem is currently being developed. It will provide not only the control of the geometry at the single pixel level, but also control over color and luminance of stitched parts. On the other hand, we are currently working on creating VR so that it will be possible to define a specific scene and working conditions for the future research.

In the future, first of all, we plan to attempt to obtain financing in the form of a grant. This would allow building a semi-transparent wall with a set of high power LEDs and thus complete the second stage of the project. This would give the opportunity to conduct research related to simulation of glare and also conduct many other works with an extended user interface.

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