Innovative Solutions for Immersive 3D Visualization Laboratory

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ABSTRACT

The paper presents results of the work concerning the technical specification of Immersive 3D Visualization Laboratory to be opened in late summer 2014 at the Faculty of Electronics, Telecommunications and Informatics at Gdańsk University of Technology in Poland. The person immersed in VR space will be placed in a transparent sphere with a diameter of over 10 feet, supported on rollers and equipped with a motion tracking system. Walking motion of the person will inflict the revolution of the sphere and trigger changes in the computer generated images on screens surrounding the sphere (CAVE with six walls) thus creating an illusion of motion. The projection system will be equipped with a 3D visualization capability and supplemented with a spatial sound generation system. The analysis prior to the specification was based on extended studies including literature and site visits to selected installations in Europe as well as consulting with companies which are leading European manufacturers and 3D systems integrators.

Keywords

Virtual reality, VR systems and toolkits, CAVEs, walk simulation, immersion.

1. INTRODUCTION

In recent years, many centers in the world attempted to build their own virtual reality laboratories. The main idea of such laboratories is to allow users to feel immersed and to move freely in a computer-generated virtual world. In particular many of these laboratories deploy sophisticated devices, allowing for unlimited territorial virtual walk [4, 7-9, 15, 18, 19].

An important advantage of virtual walk systems is their ability to generate images, scenes and situations that look very realistic, and to allow users move through the virtual world in a natural way. Thus, such systems may be used in applications such as, among others [15]:

- military training and operations,
- industrial inspection training,
- scientific and architectural visualization,
- virtual tourism, exhibitions and museums,
- measuring the impact of the environment on human behavior,
- phobia treatment,
- entertainment (e.g. computer games).

Implementation of virtual reality systems is in general a very complex task. Such systems combine a number of modules of various types: mechanical, optoelectronic and computer. Any assessment of VR system quality must take into account the properties of human visual, auditory, haptic, and balance systems.

Virtual reality is sometimes described as I^3: interaction, immersion, and imagination [2]. Interaction is provided by the input devices, immersion – by the output devices. Imagination is not associated with the devices, is concerned with the user. It is necessary to break away from the physical reality. In the case of virtual walk systems, interaction is achieved via locomotion interface, immersion – by surround audio-visual projection.

In order to provide the user with the ability to walk in the virtual reality, a number of solutions have been proposed: bidirectional treadmills [3, 6], conveyor tables equipped with an array of bidirectional rollers, omnidirectional roller skates, sliding surfaces with the mechanism of placing feet centrally, motion platforms and moving paving slabs placing automatically under the walker's feet [11, 14]. All of these systems are rather complicated and thus less reliable. Other disadvantages could be excessive noise or lack of image projection on the floor.

One of the best solutions providing movement without changing location is a freely rotating sphere with the user placed inside, where the sphere is moved only by the force of human steps (something like an omnidirectional hamster wheel) [7, 18].

In a system using a rotating sphere (with a special hatch for entry) to achieve the feeling of audiovisual immersion in the surrounding virtual reality a cybernetic helmet is usually used, e.g. Virtusphere [22]. This results, however, in a discomfort caused by the device of considerable size and weight placed on the user's head. In addition, the delay in the displaying of images in case of rapid motion of the user's head can cause cybersickness [2, 12].

An interesting device was developed at the University of Warwick (England) [7]. In this solution, rotating sphere with a user placed inside rises in a vertical air stream, creating a kind of an air cushion. The sphere consists of two layers, each of which consists of several segments of a specially designed shape [7]. In order to ensure sufficient mechanical stiffness, the segments of individual layer overlap with some offset. The outer layer of the sphere is made of brushed material thus becomes a screen on which the projection of the image is performed. The user does not have to wear anything on your head.

Unfortunately projection on the sphere was only 2D. Moreover, the problem of image bonding from different projectors has not been completely solved. Complex border line between two adjacent 2D images on a spherical rotating screen makes it difficult to combine [20]. Stereoscopy complicates the task further. Our analysis shows that only transparent sphere surrounded by the cubic CAVE guarantees proper 3D stereoscopic visualization.

The first CAVE (Cave Automatic Virtual Environment) was built in the University of Illinois at Chicago in 1992 [4, 5]. The projection in CAVE takes place on a number of flat screens, arranged in the form of a cube, typically about 10 feet at each edge. In many caves projection is made only on four (three walls + floor) or five (+ ceiling) walls. This allows the user easy access to the interior of the CAVE (through the missing wall). However, in such implementation of the CAVE the user who turns back does not have a screen with an image in front of himself. For full immersion the CAVE surrounding the sphere requires all six cube screen-walls and projection of images with suitable resolution and brightness. Of course, one wall should provide entrance to the CAVE.

2. IMMERSIVE 3D VISUALIZATION LABORATORY

The task of creating a modern virtual reality laboratory, named Immerse 3D Visualization Laboratory, has been started at our Faculty. One of the main assumptions of the laboratory is to ensure the highest possible degree of immersion feelings (unrestricted freedom of movement and stereoscopic 3D projection) together with the least amount of the equipment worn by users (e.g. virtual helmets) to provide them with the maximum comfort and impression of natural activity.

2.1 Spherical Walk Simulator

The laboratory project is partially based on the solutions described in the previous section. Implementation of a mechanism of *movement without changing location* will be carried out using a transparent sphere rotating on the rollers. A user will be entered into the sphere through a special hatch opened from the outside.

In the case of projection on screens surrounding the rotary sphere, high transparency and homogeneity of the sphere is required in order to prevent excessive distortion of observed image (Fig. 1). Therefore the sphere has to be made from a relatively small number of segments (to minimize the length of segment boundaries), from a material having sufficient mechanical strength (the need to maintain the user inside without significant deformation of the sphere), resistance to dirt and mechanical damage (scratches) during normal use.

Figure 1. Visualization of the rotary sphere inside the CAVE.

Average observer eye level should coincide with the geometric center of the sphere, which provides the direction of observation perpendicular to the surface of a sphere and to minimize the distortion of the image in the case of projection on screens surroundings the sphere (on the surface of the sphere there will be no refraction of light rays). Diameter of the sphere must therefore be equal to about two heights of the average human (up to the eye level) and was set to 10 feet. In case of placing the user inside the sphere it is extremely important (safety reasons) to ensure sufficient air volume in the sphere. For the sphere diameter equal to 10 feet the above assumption is fulfilled [15, 16]. The estimated sphere diameter provides also sufficiently large radius of curvature, therefore abnormality of movement will be imperceptible or at acceptable level [15].

The transparent variant of Virtusphere device with a diameter of about 10 feet [22] seems to meet all these required conditions.

2.2 Cubic CAVE

In our laboratory the rotary transparent sphere with a user inside will be placed in the center of the cubic CAVE with edges of about 11 feet each (3.4 meters). The CAVE will consist of four vertical acrylic flat screen-walls and horizontal glass screen-floor and glass screen-ceiling with special coating for highest brightness uniformity. To allow access to the CAVE, one of these screen-walls will be an automatic sliding door.

The 360 degree view will be achieved via the stereoscopic rear projection on the all six flat screen-faces forming the cube structure of the CAVE around the sphere [15, 16]. This solution requires projection from six different directions (Fig. 2). The whole image surround will be displayed by 12 digital projectors – two Barco Galaxy NW7 projectors per screen-wall (floor, ceiling). For seamless alignment of both projectors on each flat screen the edge blending technique will be used. These three-chip DLP projectors themselves have a resolution of 1920 × 1200 pixels (WUXGA) and thus a final resolution of single screen-face will be 1920 × 1920 pixels. Therefore, the square pixel edge length will be 0.067 in (0.17 mm) [16]. A luminous flux of the projectors equal to 7000 ANSI lumens implies (taking into account the losses caused by the edge blending) the total luminous flux above 11000 ANSI lumens per screen-wall.

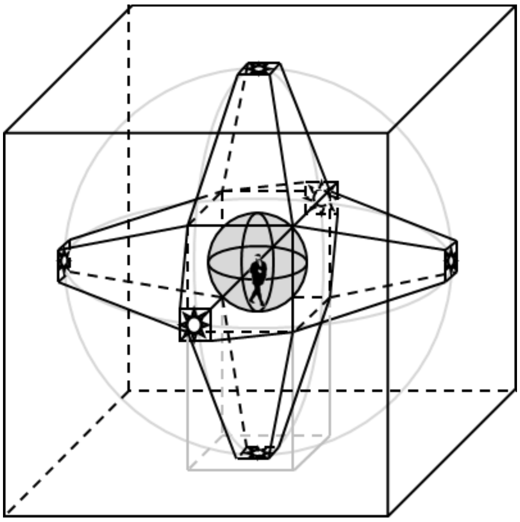

Figure 2. The rotary sphere and six pairs of projectors in I3DVL.

Three-dimensional vision is related to the fact that the eyes of an observer are located at some distance from each other, and therefore each eye catches a slightly different picture. The interpretation of these images takes place in the brain of the observer, resulting in the impression of depth. Creating an impression of depth in this manner, requires generation of pairs of images seen from a slightly different perspective, and directing them (e.g. by special filter glasses) to the left and right eye of the observer [1, 13, 17].

A few types of stereoscopic systems can be distinguished: active (the projection with separation in time) and passive ones (projection with separation of polarization or projection with spectrum channels separation). Because of the possibility of depolarization of light on the rotary sphere material, the projection with polarization separation may not work properly in our laboratory and has been rejected (Table 1). Two other alternative methods were chosen to implementation: separation in time with active shutter glasses (alternating eye overriding, Fig. 3) and spectrum channels separation using passive glasses with selective interference filters for each eye at the appropriate wavelength.

stereoscopy	advantages	disadvantages
active with separation in time	wide color space standard projector 120 Hz without additional equipment	possibility of flickering, polarization sensitive, active glasses (shutters)
passive with separation of polarisation	wide color space, no flickering, passive glasses	polarization sensitive, projectors with polarizing filters
passive with spectrum channel separation	no flickering, passive glasses, polarization insensitive	reduced color space, projectors with color filters

Table 1. Properties of stereoscopic techniques.

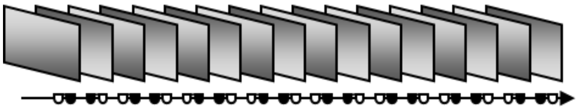

Figure 3. Active stereoscopy with separation in time.

Stereoscopy with separation in time implemented in our laboratory will use radio-based active stereo nVidia 3DVision Pro shuttering at 120Hz. Today's active shutter glasses use polarization, so there is some risk of incorrect operation of glasses caused by possible change of polarization by the rotary sphere material. Therefore, the stereoscopy with spectrum channels separation will be available as an alternative. It will be the Barco active Infitec+

technology using high-quality dynamic color filtering to produce from one projector separate images for the left and the right eye (Fig. 4) [1, 10, 13]. Additionally, slightly different color spaces of both images are fully corrected by DynaColor (Fig. 5). As the incorporated active Infitec+ filter can be switched off, the same projector Barco Galaxy can also be used for standard active stereo projection, which requires synchronized shutter glasses, and for mono projection. It means that for deploying both stereoscopy only one set of projectors will be needed (but two sets of glasses).

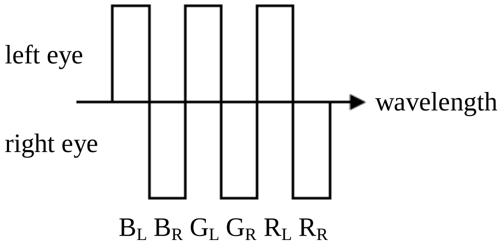

Figure 4. Spectrum channels separation in Infitec+ technology.

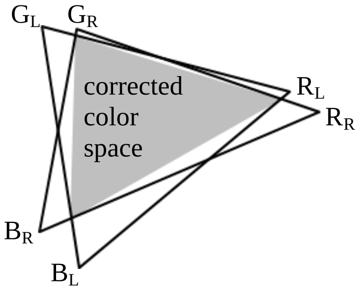

Figure 5. Color correction in Infitec+ technology.

The 12 Barco Galaxy projectors will be driven by a 12-node visualization cluster (12 × Dell Precision T3600) with 12 nVidia GPUs of the latest generation (Quadro K5000). Two additional nodes will support tracking (including spherical walk simulator) and the generation of sound. The nodes will be connected by a high performance Infiniband network and additionally by Gigabit Ethernet network.

Visualization will be supported by sound generated by Bose and Apart speakers. User's head position will be measures by ART IR-optical tracking system.

It is worth adding that the rotary sphere will be removable from the CAVE. This will allow the testing of other models of locomotion interfaces, like improved spheres or sliding surfaces with the mechanism of placing feet centrally (e.g. Virtuix Omni [21]). It will be also possible to use our CAVE in the typical way, without any walk device, only with some handheld controller. In addition, the removed rotary sphere enriched with a virtual helmet can simultaneously allow for independent simulation (like Virtusphere [18, 22] mentioned before).

3. CONCLUSIONS

Implementation of Immersive 3D Visualization Laboratory is a very complex task. Several problems of different nature: mechanical, optoelectronic and computer must be solved. Most of these problems cannot be considered separately, for instance problems related to the projection system cannot be considered in isolation from problems related to the mechanics or computer generation and synchronization of three-dimensional image.

The description above concerns mainly the problems related to the locomotion interface and the visualization of three-dimensional image. A number of problems are still not solved, both on technical matters and the subjective user perception of 3D impression as well as the impact on user health and well-being [2, 12].

Technical problems relate mainly to define the minimum required resolution and brightness and requires field tests. Another difficult problem is prediction of the impact of transparent sphere (but composed of segments) and problems concerning dynamic parameters (proper synchronization user motion with projected image) on the quality of the image.

Figure 6. Architectural visualization of the I3DVL building.

Figure 7. Construction of the I3DVL building (September 2, 2013).

The final result of the project will be a complete virtual reality laboratory (Fig. 6, 7, 8). The greatest challenge of this laboratory will be unlimited walk through computer-generated virtual world. This will create endless possibilities to implement scenarios for a wide range of practical applications.

Figure 8. I3DVL building almost ready (March 7, 2014).

4. ACKNOWLEDGEMENTS

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