

Applications of Immersive 3D Visualization Lab

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ABSTRACT

The paper presents Immersive 3D Visualization Lab (at the Faculty of Electronics, Telecommunications and Informatics at Gdańsk University of Technology in Poland) and its applications prepared after its launch in December 2014. The main device of the lab is a virtual reality cubic cave with six screen-walls, where a person can navigate in virtual space using different controllers. The most sophisticated controller is a freely rotating transparent sphere, supported on rollers and equipped with a motion tracking system (something like an omnidirectional hamster wheel). A person's walking motion causes the sphere to revolve and triggers changes in the computer generated 3D images on VR cave screens surrounding the sphere, thus creating an illusion of motion. The projection system is supplemented with a spatial sound generation system.

Keywords

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

1. INTRODUCTION

Similar to many universities in the world, Gdańsk University of Technology in Poland decided to build their own virtual reality laboratory. The main idea was to allow users to feel immersed and to navigate freely in a computer-generated virtual world. We wanted to ensure the highest possible degree of immersion (unrestricted freedom of movement and stereoscopic 3D projection) while reducing the amount of equipment worn by users (e.g. virtual reality helmets) to provide them with maximum comfort and impression of natural activity.

Virtual reality is often described as I^3 or $3 \times I$: interaction, immersion, and imagination [1]. Interaction relates to the input devices, immersion – to the output devices. However imagination does not concern the devices, it is associated with the user. He or she should not be distracted by the physical reality.

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In the case of virtual reality caves [3, 4, 8, 15], interaction is achieved with navigation controllers (from wands to locomotion simulators), immersion – via surround audio-visual projection.

Virtual reality caves are intended to generate scenes and situations that look very realistic and to allow easy navigation through them. Moreover the sophisticated locomotion interface allows us to move through the virtual world in a natural way. Thus, VR caves may be used in applications such as [11, 12]:

- military/rescue training and operations,
- industrial inspection training,
- scientific and architectural visualization,
- virtual tourism, exhibitions and museums,
- analysis of human behavior,
- phobia treatment,
- entertainment (e.g. computer games),
- telepresence.

Projection in virtual reality caves takes place onto flat screens arranged in the form of a cuboid. The majority of VR caves have only four screens: three vertical walls and a horizontal floor. This allows a user to easily access the interior of a VR cave. For full immersion though, a VR cave should have six rectangular screen-walls (one as a gate). To provide users with the ability to walk on their own feet through the virtual scene, without changing physical

location, a number of devices have been proposed [2, 5, 9]. One such device is a rotary sphere with the user in the middle [6, 7, 14, 17]. Its transparent surface allows us to use it inside the VR cave and see a virtual scene (projected onto the screens) without need to wear an uncomfortable VR helmet.

2. IMMERSIVE 3D VISUALIZATION

The Immerse 3D Visualization Lab contains a virtual reality cave in the form of a closed cube with edges of about 3.4 meters each. It consists of six square screens: four vertical walls, a horizontal floor and a ceiling. All screens are two centimeters thick acrylic plates with special coating for highest brightness uniformity. The floor is strengthened with an eight centimeters thick glass plate with a carrying capacity equal to 700 kg (7 persons). To allow users entrance to the VR cave, one of the screen-walls is an automatic sliding gate (Fig. 1).

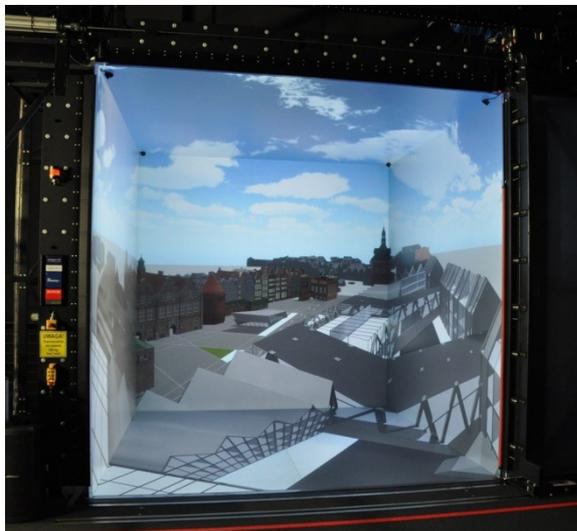


Figure 1. VR cave in I3DVL (with open gate).

The 360 degree view is achieved by the stereoscopic rear projection onto all the six flat screen-faces of the cube [12, 13]. It requires projection from six different directions. In order to cover each whole square screen two Barco Galaxy NW7 projectors with the use of the edge blending technique are applied per screen.

Twelve three-chip DLP digital projectors, with WUXGA resolution (1920×1200 pixels) and 7000 ANSI lumens luminous flux each, produce six images with the final resolution equal to 1920×1920 pixels and the total luminous flux above 11000 ANSI lumens each (taking into account the losses caused by the edge blending). The square pixel side length equal to 1.77 mm implies the 0.06 degree (3.6 minutes of arc) size of pixel seen from the center of the VR cave [10, 12, 13].

The Barco Galaxy projectors can use two alternative methods of stereoscopy: separation in time with

active shutter glasses (nVidia 3D Vision Pro) and spectrum channels separation using passive glasses with selective interference filters (active Infitec+). Both methods need a frequency of 120 Hz (i.e. 60 Hz per eye).

The dozen Barco Galaxy projectors are driven by 14 Dell Precision T3600 computers with nVidia Quadro K5000 GPU each. Twelve of these computers generate images directly for the projectors, the remaining two are in charge of synchronization, tracking done by ART IR-optical tracking system and the generation of sound for Bose and Apart speakers. The computers are connected by two networks: 40 Gb/s InfiniBand and 1 Gb/s Ethernet.

The computers of the virtual reality cave can communicate directly, through the fast optical fiber InfiniBand connection, with the high performance Academic Computer Center in Gdańsk (CI TASK) [18]. It allows for real time visualization of very complex calculations (e.g. physical simulations or artificial intelligence).

A user in the middle of the virtual reality cave may navigate using different controllers. The simplest one is a handheld wand (flystick), where the user steers movement with a joystick and buttons. More sophisticated controllers allow the user to navigate by his own steps.

The Immerse 3D Visualization Lab contains the spherical walk simulator Virtusphere [17] that has the form of a transparent (openwork) sphere rotating on rollers. It can be inserted into the center of the virtual reality cave (Fig. 2) and is entered afterwards through a manhole. The user sees images that are projected onto the screens surrounding the rotary transparent sphere. The diameter of the sphere is equal to 3.05 m and provides a sufficiently large radius of curvature, therefore the abnormality of movement will be imperceptible or at acceptable levels [10, 12]. Moreover, the user's head is almost in the geometrical center of the sphere.



Figure 2. Spherical walk simulator in the middle of VR cave in I3DVL (with open gate).

Instead of the rotary sphere other walk simulators (but lighter than 600 kg) can be used. This will allow other models of locomotion interfaces to be tested, such as improved rotary spheres or sliding surfaces with the mechanism of placing feet centrally (e.g. Virtuix Omni [16]). It is worth adding that all these walk simulators (including spherical) can work without the VR cave, just with a virtual reality helmet.

3. APPLICATIONS

The unique combination of hardware in Immersive 3D Visualization Lab makes it possible to execute different simulations. The first year of the lab's operation yielded numerous VR applications: some of them are results of applied research, others have been prepared during student projects.

Military and rescue training and operations

It is much cheaper and safer to simulate battlefields and rescue operations (such as fires, floods, earthquakes) with virtual reality, as opposed to real training grounds. Infantrymen, firemen and other specialists can train the procedures using virtual reality. I3DVL has not yet had the opportunity to cooperate with uniformed services, though we do have a number of indoor and outdoor locations modeled. Some of them include scripted events, objects that can be interacted with, as well as AI controlled agents. One example is a student's application where one can attempt to catch horses on an enclosed meadow (Fig. 3).



Figure 3. Virtual horse catching simulation.

Industrial inspection training

Similarly, virtual inspection of ships or buildings is safer and less expensive than on physical training grounds. With the cooperation of one leading international certification body and classification

society (DNV GL), I3DVL began work on the adaptation of its ship inspection simulator to the VR cave. At the time of this writing, it is possible to view a 3D boat model and streamlines of airflow simulated beforehand around sailboats (Fig. 4). Work on a larger vessel is under way.

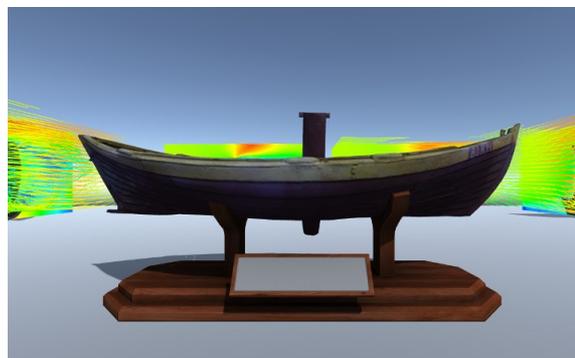


Figure 4. Ship sightseeing simulator.

Scientific visualization

Virtual reality provides very useful tools for different scientific applications. For example, chemists from our university requested an application that allows for visualization and manipulation of chemical structures (e.g. proteins, enzymes). At the moment, an application is being developed for the presentation of 3D structures described in the Protein Data Bank (PDB) format (Fig. 5).

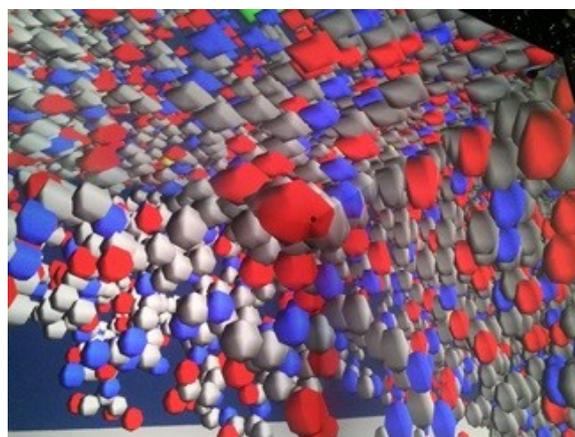


Figure 5. Protein Data Bank structure presenter.

Architectural visualization

The Coal Market Square is a historical part of Gdańsk. The area is being redesigned and a new gallery is planned. Architects have come up with many designs, three of which have been modeled. I3DVL allows the governing decision makers to see the submissions for themselves and walk through virtual galleries and the Coal Market Square itself (Fig. 6). It is possible to switch between day and night, move freely or choose a point of view such as from the roof of one of the buildings, or start a virtual tour along a premade route.

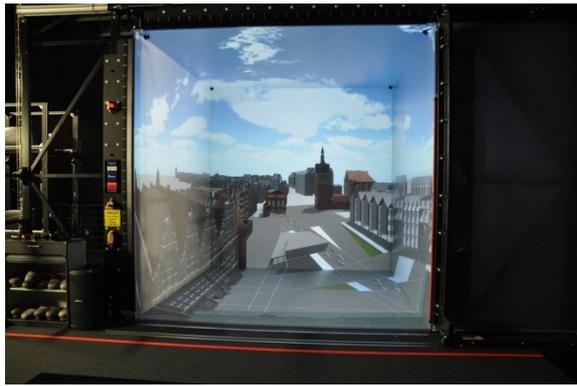


Figure 6. The virtual Coal Market Square.

Virtual tourism, exhibitions & museums

A masterpiece created by eighteenth century craftsmen in Gdańsk, the Amber Room, was considered one of the most valuable works of art ever created in Europe. Until its mysterious disappearance during World War II, its history took place in Berlin, Tsarskoye Selo (for over two centuries) and finally Königsberg. It took 24 years between 1979 and 2003, to reconstruct the room in Tsarskoye Selo, although there was a major division between the craftsmen over the question whether the new room should be artificially aged, with the proponents ultimately winning. In I3DVL we can admire the Amber Room as an example of immersive virtual tourism (Fig. 7). This also shows how the laboratory could be used by museums to plan and test expositions before building them, or by artists who might want to see how their sculpture or other form of art might look in a specific room, or even how changing the different parameters (such as material or age) would affect the final look.



Figure 7. The virtual Amber Room.

Analysis of human behavior

Observing how people react in an immersive virtual environment can provide a lot of useful information. One could for example present planned products to customers and assess their attractiveness from their reactions. A group of psychology students from

University of Social Sciences and Humanities developed scenarios for a game that should help in the treatment of acrophobia (fear of heights). Two applications were developed by students, one where a person can ascend high skyscrapers to measure at what heights he begins to feel uncomfortable. The other included coins placed on rooftops, ledges and glass bridges and measured fear of height by the number of coins a user was able to collect (Fig. 8). This could provide psychologists with valuable insight. While final versions of this software prevented people from actually falling off the edges, the ones that allowed it showed varying levels of reaction from people, with some people largely unaffected, while others experienced strong emotions.



Figure 8. Acrophobia treatment by gamification.

Phobia treatment

A number of anxiety disorders and phobias can be treated through controlled exposure to the real phobic stimuli (flooding technique) or to its image in the patient's brain (implosive therapy). In I3DVL, virtual stimuli can be used instead of real or imagined ones. For example, arachnophobia can be treated by controlled exposure to a virtual spider in different forms and situations (Fig. 9), peristerophobia – to a virtual pigeon, glassophobia – to a virtual crowd, acrophobia – to a virtual height. Wandering on virtual ledges and floors of a skyscraper allows a patient to overcome their fear of heights.



Figure 9. Virtual implosive therapy.

Entertainment – computer games

I3DVL is a very attractive platform for the development of games focused on movement through different terrains. We present a game made by students, taking place in an old hospital, where a player escapes from zombies (Fig. 10). The main focus of this game was to test different navigation schemes. For example, the forward direction could be determined based on the direction a player is looking, or the direction he is pointing the controller. Another option was to use the player's position in the VR cave (i.e. how much off-center they are and in what direction).



Figure 10. Escape from zombies.

Telepresence

I3DVL can display not only a virtual, computer-generated world, but also photos and video recordings (Fig. 11). This can also be done in real time, allowing users to feel as if present in a distant, possibly dangerous, place. Telepresence could be used to control robots, giving the operator 360 degree view (assuming the robot has appropriately placed cameras). This would be immensely useful for operations in dangerous environments, but also any other situation where the user cannot be physically present at the chosen location.



Figure 11. Real scene projected onto cave screens.

4. DIRECTION OF DEVELOPMENT

Currently, the laboratory is expanding in a number of ways, such as installation of new hardware and development of new software. For example, enabling more users to interact at the same time with the

virtual world will require both hardware and software solutions.

Hardware development

New equipment will allow developers (e.g. students) to test their projects on a smaller VR cave with only three walls and a floor, so that the main VR cave is only used when projects are nearing completion. Initial programming work can be implemented on single-computer stations, or a 4-computer mini VR cave built on the basis of four monitors. All the computers controlling these devices have identical hardware and software configuration. The clusters supporting the VR caves have the same network architecture (InfiniBand and Ethernet). This solution allows developers to use scalability rules during development of virtual reality applications.

Interaction development

The VR caves will be equipped with more wands and markers, which will allow extensive interaction and accurate tracking of groups of users and their gestures. Further improvements are planned to make movement in the spherical walk simulator more natural. We are also looking for ways to improve the collisions with virtual obstacles – it is easy to detect the collisions thanks to the user's position given by tracking devices, but responding to collisions is problematic. If a user tries to walk into a virtual wall (by physically stepping forward), we can't stop him – we can either allow him to walk through the wall, or we can push the wall away, but both solutions break immersion. The virtual amber room worked around the problem by resizing the room to the exact size of the CAVE, thus placing virtual walls where the physical screens are located. The problem of reduced immersion can also be alleviated by making colliding objects appear fluid when approached closely. In addition to the above solutions, visual and audio feedback can be given to users when they collide with objects. Haptic feedback would increase immersion, but we are yet to acquire any haptic devices for our lab. Similarly, interaction with the virtual world may seem less or more natural depending on the controllers used and how the application reacts to the inputs, so there's plenty of work that can still be done to find solutions that work best for the given scenarios.

Software development

Development of software applications for the VR caves requires appropriate development frameworks. Dedicated tools are very expensive (e.g. VBS), so we are negotiating conditions for obtaining them for educational and research purposes. On the other hand, standard environments for game development (e.g. Unity) tend to be useful, especially since their cost is relatively low, but they require specialized

libraries for synchronization of image generation on each VR cave screen. Despite the fact that we already have a simple library for Unity projects, we are working on a new, improved library and framework that will be more robust and extensible. Additionally, we want to expand it to support connections with other VR devices (caves, helmets, vehicle and flight simulators etc.) to manage distributed VR simulations. The framework should also support usage of the high performance cluster (CI TASK) to execute complex calculations (nontrivial physics, advanced artificial intelligence, prediction of user behavior etc.) Once our library is ready for use we will also be able to make meaningful performance measurements to see the full capabilities of our CAVE's hardware (the temporary Unity library we're using experiences major slowdowns with stereoscopy active).

5. CONCLUSIONS

Immersive 3D Visualization Lab is a complete virtual reality environment. The greatest advantage of this laboratory is the possibility to walk through a computer-generated virtual world without limitations. This creates endless capabilities to implement scenarios for a wide range of practical applications. The first year of I3DVL's operation proves that virtual reality is a powerful tool for different human activities.

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