Collaborative Virtual Reality Usage in Educational and Training Process

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Abstract –This paper focuses on a utilization of advanced virtual reality approaches and technologies as especially progressive tools in the context of online education, training and testing. The purpose of the utilization is to allow easier, faster and more attractive education and training in the areas containing topics and concepts that are not easy to comprehend or that are too expensive to be carried out in the real world. The paper explores collaborative virtual reality and its role in online education, primarily from the LIRKIS G-CVE utilization point of view. LIRKIS G-CVE is a web-based collaborative virtual reality system, based on the A-Frame and Networked-Aframe software solutions. LIRKIS G-CVE is described and three of its educational and training applications are presented: virtual environments for a university course dealing with virtual reality, an environment for patient rehabilitation and another one for an industrial training. Plans for LIRKIS G-CVE utilization in elementary, secondary and high school education are outlined, too.

I. INTRODUCTION

Modern information technologies penetrate almost every aspect of our lives. Virtual reality and related technologies [1] are also a part of this phenomenon. The recent COVID-19 pandemic situation noticeably increased the importance of online learning. There is a growing demand for more interactive and smart solutions and online learning is starting to be preferred even in the areas dominated by the classical approaches. The online education has relatively good results in its current form, where it offers digital content using standard multimedia (audio, still images and video). However, to explain more challenging concepts from areas such as physics, biology, chemistry or history, it would require significantly more interactive presentation of the content. One of the most developing technologies that could significantly increase the level of interactivity is virtual reality (VR) [2].

Research and development activities related to the utilization of VR in online education are one of the priorities of the LIRKIS laboratory at the home institution of the authors. The LIRKIS laboratory (Laboratory of Intelligent Interfaces of Communication and Information Systems) is an excellent laboratory for research, development and teaching applications in the area of parallel, distributed and networked computing systems for solving computational problems in the processing of graphic data and virtual reality with a primary focus on information systems and visualization, intelligent interfaces and human-computer interaction in the context of HCI and HCM-T [3].

The online learning - related activities carried out at LIRKIS try to use virtual reality technologies for simpler, faster and more effective learning process, including communication between students and educators. They focus on the collaborative, or shared, virtual reality where the participants can not only immerse into virtual environments but also communicate with each other. For such immersion and collaboration we developed LIRKIS G-CVE (Global Collaborative Virtual Environments), which is based solely on web technologies. This means that a user needs only a web browser to use the environments.

In the rest of the paper we explore collaborative VR and its role in online education, primarily from the LIRKIS G-CVE utilization point of view. It is organized as follows: Section II overviews the current state of collaborative VR with respect to two main ways of delivering immersive VR content – CAVE facilities and VR headsets. Section III deals with LIRKIS G-CVE and section IV describes selected cases of its deployment in training and education. The conclusion outlines plans for its future utilization in this area.

II. COLLABORATIVE VIRTUAL REALITY

A virtual environments usage expands the possibilities of user collaboration in real-time. According to Flavian et al. [4], collaborative systems represent a specific architecture and technological equipment for a creation of collaborative activities. The authors of [5] emphasize the need for a physical or virtual (in a form of avatars) presence of users in collaborative environments. The basic types of collaborative VR environments are systems based on Cave Automatic Virtual Environments (CAVE) and systems based on VR headsets (data helmets).

The basic goal of VR CAVE systems is to immerse the whole body of the user into a virtual environment (VE). They are usually designed for more than one user, so users may collaborate in VE naturally, as in the real world. Another advantage of VR CAVEs is that 3D objects are displayed in the realistic scale with respect to the users [6]. From the point of view of Muhanna [7], a VR CAVE system can be considered as hardware or software expandable to support a wide range of technologies - hardware and software subsystems. However, the subsystem for external components integration must be reliable and robust. Then the quality of the system and module compatibility and the possibility of system adaptation with respect to various input subsystems, modules and devices are increased. Utilization of VR systems increases the need for natural interaction between the user and VE. In the case of collaborative environments, it is important to mediate the natural interaction between all users in real time. According to [8], in a virtual CAVE system, the way of natural interaction between users is highly efficient and realistic. Natural collaborative bonding involves all sensory immersion without the need to implement virtual avatars. Users collaborate in a physically shared space where they really see each other. Communication between the users is realized in a natural way and there is no need to use an external technology for communication channels. From the point of view of the basis of natural communication, the interaction between users is intuitive without the need to learn gestural, voice or touch control. Probably the most significant disadvantage of CAVE systems is their cost, both to build and maintain a CAVE. Another disadvantage is that the space inside a CAVE is limited, usually to about 5 to 10 people. It should be also noted that the perception of the 3D environment is different from different spots inside the CAVE. The perception can be fixed by using so-called off-axis projection for VE rendering, which, together with user position may provide perfect perception from any point inside the CAVE. However, such fix will work for one user in the CAVE only, which makes natural collaboration inside a CAVE uncomfortable.

The second approach uses VR headsets, also called data helmets or head mounted displays (HMD). One headset provides VR experience for one user only. This means that when multiple users wish to collaborate in a VE, each of them has to wear a headset. The development of VR headsets focuses on increasing the performance while decreasing the size, weight and power consumption. They represent cost-effective alternative to VR CAVEs.

A VR headset usually depends on an external computational unit (a computer) that processes input from the headset and produces an audiovisual output, played and displayed by the helmet [9]. The headset and the computer communicate via full duplex channels. As high transmission rate is required, the communication is usually realized by a data cable. Some headsets, such as Oculus Quest or Microsoft HoloLens, have an integrated computational unit, so no cable connection with an external one is needed. This increases the user comfort but limits the system performance. As in the case of CAVEs, VR headsets are, in principle, extendable by additional modules and subsystems.

The concept of collaborative environments in the VR headset-based systems is built upon the possibility of sharing the same VE by multiple users in the same time. It is important to be able to process input data from each user individually. In the end, each user in a group sharing the VE should be able to realize its own inputs (activities) without blocking the activity of other users. The usage of headsets makes it possible to separate the users physically while they share the same VE. For each user, his or her interaction with the VE is unique and observable by other users in the same VE. As the users usually do not see each other in the real world, they are represented by 3D objects, called avatars, in the VE. From the VE distribution point of view, the users may share the same physical space or may be connected via a computer network (Internet) [10]. VR headset-based collaborative virtual environments are limited by the number of users connected in the same time. If we have a VE, shared by n users (u_1 to u_n), then adding a new user u_{n+1} increases the load of systems of u_1 to u_n as they now have to render also the avatar of u_{n+1} and possibly perform other computations related to it. Of course, it also increases the load of the computer system managing the VE and its users.

Contrary to CAVE systems, the possibilities of natural, physical, interaction between users with VR headsets is very limited. It is only possible if the users share the same physical space and the headsets have see-through displays or other means to capture the surrounding environment and mix it with the representation of the VE. In other cases, alternative means have to be implemented. One of the most significant problems of user communication is the representation of hands and their animation. To provide the most natural representations of hands and arms, additional devices (controllers) are used. They determine the position of the user's hands precisely and make it possible to compute a skeletal model of the hands and arms, which allows rendering their believable representation in the VE. To decrease performance requirements, simple models are used. The need to animate hand and arm movements may significantly contribute to the load increase when more users join the VE: Each movement of an arm, hand or a finger of any user should be rendered to be seen by other users [11]. To improve the system performance, an approach where only the hands of the headset user have detailed animation is often used. For the avatars of other users, which he or she sees inside the VE, only simplified models are used (e.g. fingers don't move).

One issue related to collaborative VR is how to manage real-time manipulation with objects in a shared VE. The authors of [12] prefer that only one user can manipulate with an object at given time moment and it is the responsibility of the corresponding VR system to decide which user will be allowed to interact with the object. The reason for this is to prevent collisions and blocking of the object by simultaneous attempts to manipulate with it. According to [13], blocking the interaction with the shared object for all users except one is not an ideal approach for collaborative VR. However, allowing multi-user interaction requires a software component that calculates the combined effect of the interactions and updates the object accordingly. Considering online learning context, a variation of the first approach may be suitable for most of the scenarios. The variation dwells in selecting a user that is the only one able to manipulate with the object while the other ones only observe it. In online learning, this user will be the teacher. In addition, the teacher may be able to pass the rights to manipulate with the object to another one, representing a student. It is also possible to allow each user to manipulate with his (her) copy of the object.

III. LIRKIS GLOBAL COLLABORATIVE VIRTUAL ENVIRONMENTS

The LIRKIS G-CVE (Global Collaborative Virtual Environments) [14], [15], developed by and under the supervision of the authors, represents an immersive VR system, which utilizes web technologies to provide multi-user connection. Its architecture (Figure 1.) is based on the Entity-Component-System software architectural pattern, which offers high flexibility to create various VR applications and extensions of CVE on different complexity levels. Each entity can contain multiple, fully reusable components, which can be mixed according to the final use. Considering that the LIRKIS G-CVE is supported by web technologies and services, it is only natural that the JavaScript programming language has been chosen for its implementation stage. The communication between the system and users is based on client-server architecture to share data over the network. The LIRKIS G-CVE provides client-side rendering (CSR) to be able to process more complex virtual environment with a variety of visual effects, lights and shades.

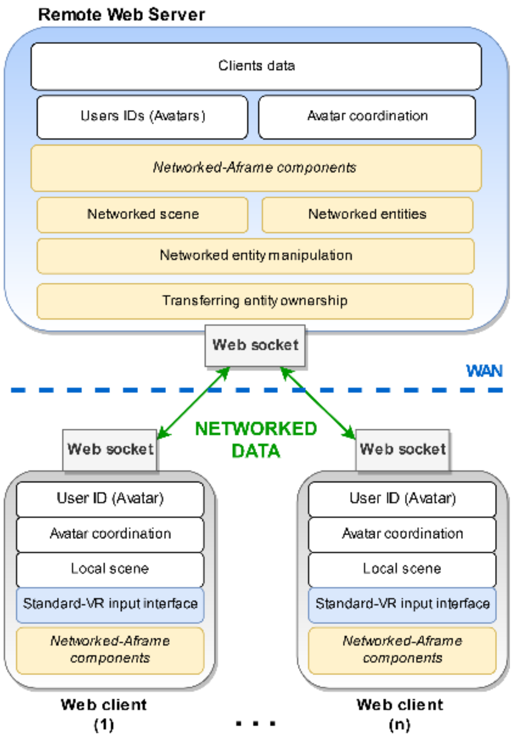


Figure 1. LIRKIS G-CVE system architecture

Users can share the virtual environment (their avatars) no only visually. In LIRKIS G- CVE, users can manipulate the environment using three interaction methods. The first type of interaction was implemented using ray-casting method (Figure 2. a). The Raycaster [16] includes a 2D line extended from a user towards the direction where it checks its intersection with surrounding objects (Figure 2. b). Because of this feature, it is possible to move the object in a way similar to a 3D pointer or a laser control. A 3D object can be selected and then manipulated. The second type of interaction involves 3D object collision detection between the user and the surrounding scene (Figure 2. c). Each collision is processed by 3D volumes called bounding boxes (3D colliders) that wrap around the objects [17]. The 3D collider can be formed into various shapes such as a primitive box, a cube, a sphere or a cylinder. Utilization of 3D colliders positively affects object selection and manipulation through 3D pointers and VR hands, which can collide with surrounding objects.

Thanks to the fact that LIRKIS G-CVE is implemented using standard web technologies (primarily JavaScript and HTML), it can be deployed on virtually any computing machine that offers a web browser (e.g. PC, Android mobile devices, IoS mobile devices, MS Hololens or Oculus Quest) without the need to install any additional software.

a)

b)

c)

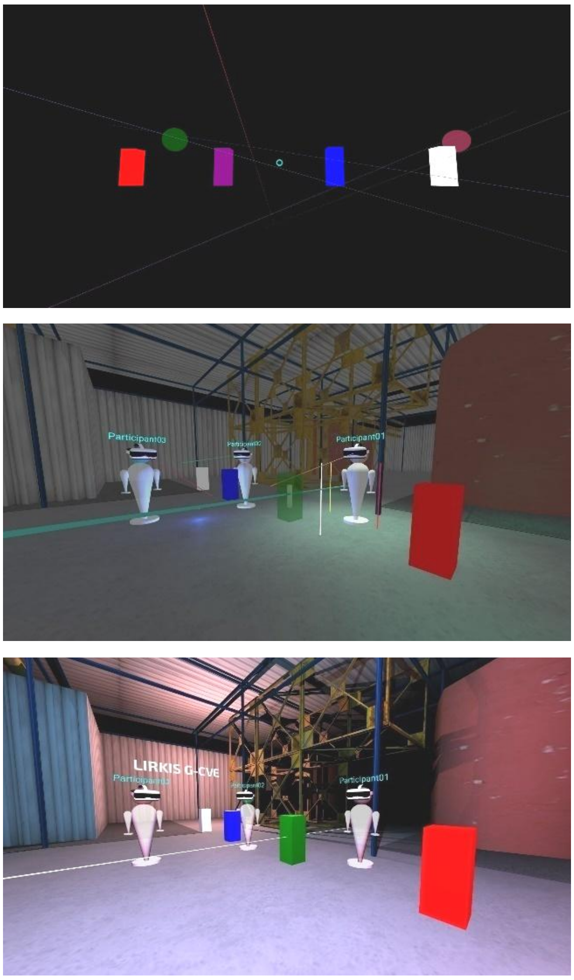


Figure 2. The LIRKIS G-CVE Smart-client interface (SCI): a) SCI Raycaster intersection. b) Hand and gaze-based interaction. c) Bounding volumes collision detection.

IV. LIRKIS G-CVE IN EDUCATION AND TRAINING

The aforementioned properties of LIRKIS G-CVE make it very suitable for both education and training. It is therefore no surprise that it has been already employed in such activities.

A. University Courses

LIRKIS G-CVE is integrated to the Virtual Reality Systems master course at the home institution of the authors and it is also a subject of several diploma theses under their supervision. Via LIRKIS G-CVE, students learn how to develop their own virtual environments. After creating the environments they can add various features, such as animations, colliders or scripted events. The students may share their creations with classmates and friends and let them test the environments. Teachers can enter the environments for evaluation. In addition, teachers use special, educational, shared virtual environments for step-by-step explanation of individual features of virtual objects, for example how to implement and use a raycaster in real time.

Figure 3. One of the virtual environments, available via LIRKIS G-CVE, as used in the Virtual Reality Systems master course: overall view (left) and view from the Student2 position (right).

Provided that VE are hosted at a site offering an online integrated development environment (e.g. https://glitch.com/), teachers can also check and correct students' source code in real time. Because the VE and corresponding source code are available online, the teachers can switch between online and offline (classical) form of teaching instantly, without any problems. The only difference is that online communication tools, such as Cisco Webex, Microsoft Teams or Google Hangouts, are used instead of direct, person-to-person communication. Such form of online education with LIRKIS G-CVE has been successfully carried out during the recent pandemic situation in the summer semester of 2020. An example of a VE used during the semester can be seen in Figure 3.

B. Patient Rehabilitation

A project for a rehabilitation (training) of patients after a stroke, who lost control over one arm, is another case of LIRKIS G-CVE usage. Both the patient and the therapist can cooperate in virtual therapy environment (Figure 4.) without the need to share the same physical location.

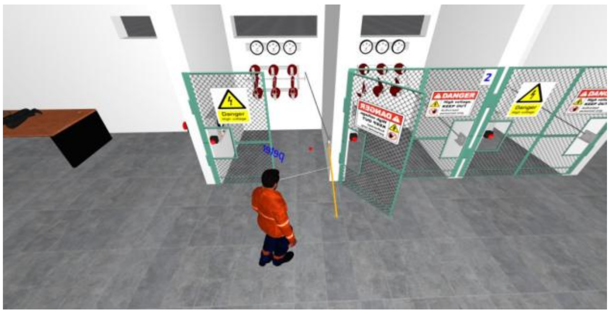
Figure 4. Patient's view during the rehabilitation process using LIRKIS G-CVE.

The virtual environment in this context is intended to replace a mirror where the patient sees his or her healthy arm and can image controlling the paralyzed one. In the VE, the patient sees a virtual representation of the paralyzed arm, which moves according to the brain activity of the patient. This LIRKIS project uses virtual and mixed reality hardware such as Oculus Quest or MS HoloLens and a built-in web browser. The patient performs the training following the therapist's instructions. The therapist is able to observe the training activity and instruct the patient in real time. Unfortunately, this application cannot completely replace the patient's full rehabilitation process and, of course, its success depends on the patient's overall condition and diagnosis.

C. Industrial Training

LIRKIS G-CVE is also about to be used for employee training in an industrial environment. In cooperation with a partner from the area of electricity distribution a virtual environment for its new employees training is under development. The motivation to develop such environment comes from the current situation, where two approaches to the training are commonly used. The first one is a theoretical course and the second one is a practical training on real devices. Both approaches require noticeable resources and time. In addition, the theoretical lectures don't deliver adequate results in many cases. On the other hand, the real working environment should be an ideal one for the training but such practical approach requires reserving the real environment for the training and a presence of experienced employees (instructors) who oversee the training. Utilization of virtual environments has the advantage of providing a practical training without the need to allocate real workspace or instructors: The VE can offer an animation, which explains how to carry out the corresponding task correctly and scripts, together with triggered events, can be used to guide the employees during an interactive part of the training where they try to perform the tasks by themselves. Another advantage of VE utilization is elimination of the risk of accidents during the training. As in the previous cases, there is no need for the trainees and instructors to be at the same place physically. In fact, as mentioned above, the presence of the instructors is not required for the significant part of the training.

The current state of the training virtual environment, developed within LIRKIS G-CVE, can be seen in Figure 5. The environment offers a virtual form of real electrical devices with which the trainees interact. It also allows creating specific scenarios with custom evaluation criteria. In addition, it is possible to record the training process and replay it from different points of view. They include the position of the trainee, the instructor position and several pre-set cameras, such as a high-angle shot.



a)

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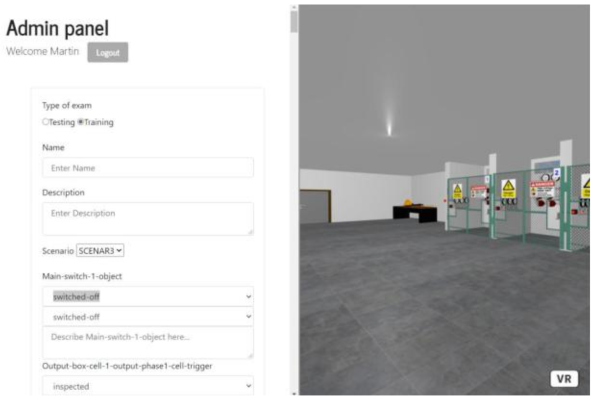

d)

Figure 5. LIRKIS G-CVE employee training environment: a high-angle shot with an instructor in front of electrical devices (a), the electrical devices as seen by a trainee (b), replay of a recorded training with controls on the left (c) and administration screen with a scenario settings dialog (d).

V. Conclusion

As it has been shown, LIRKIS G-CVE is a suitable solution for online collaboration in web-based virtual reality, with a variety of application areas in mind. While the patient rehabilitation and industrial training environments can be considered experimental and under development, the environments used for the Virtual Reality Systems (VRS) course offer a ready-to-use solution for online education, proved during the onset of COVID-19 emergency.

Regarding future applications of LIRKIS G-CVE in the area of education, we would like to focus on elementary, secondary and high schools. Here, we plan to prepare virtual classes, which will deal with more complex topics that can be demonstrated in a form of interactive presentations or experiments. In principle, the utilization of LIRKIS G-CVE in this context will be similar to the one in the VRS course and tools for online communication will be included to provide full-featured online learning. We intend to prepare the environments not only for healthy pupils but also for handicapped ones, following our long-term cooperation with Pavol Sabadoš special boarding school in Prešov, Slovakia.

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