Utilizing Virtual Reality Technologies For Advanced Training In Safeguards Verification

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Abstract— **The paper investigates the use of virtual reality technologies in educational environment related to nuclear knowledge and assesses their applicability to IAEA training for on-site verification activities. This topic is relevant due to the continued need to implement the safeguards verification process, in which activities at nuclear facilities play a crucial role. As of 2020, 2,856 on-site inspections totaling 12,767 days have been conducted. The need for ongoing training and professional development remains a significant challenge.**

Regulations require that future safeguards professionals complete a minimum of 32 hours of documented time per calendar year in their specific discipline to maintain proficiency in site configuration. Continuous retraining of existing professionals is also required to keep theoretical and practical skills sharp throughout their tenure. New training methods, such as the use of digital learning tools utilizing virtual reality (VR) technologies, can offer great advantages over traditional methods. This approach offers the opportunity to deploy practical inspection work scenarios, as virtual reality technologies allow for a high level of detail and visualization. Virtual environments also offer some advantages such as cost and risk reduction. Therefore, it is paramount to create tools that take into account cognitive task analysis (CTA) methods and techniques to help quality assurance professionals cope with the challenge of dynamic adaptation in solving the problem of dynamic adaptation to maintain organizational performance at a sufficient level. In this article, authors evaluate the applicability of virtual reality technologies based on the studies of virtual reactor plant models created at the National Research Nuclear University Moscow Engineering Physics Institute (NRNU MEPhI), as well as the experience of implementing a virtual reality laboratory for training specialists in the field of digital engineering.

Keywords: virtual reality, safeguards verification, virtual reality simulators.

I. Introduction

Examining the use of virtual reality technology in nuclear training environments, this article assesses its applicability to IAEA training for on-site verification activities. The training process for engineers in a wide variety of fields in the nuclear industry is already being transformed with virtual reality technology. This significantly reduces the cost of training and increases its effectiveness.

For example, despite the safety and reliability of nuclear power plants, they are still prone to possible accidents due to human error [1]. Previously, in order to level out the impact of human error, it was necessary to conduct costly training on real facilities or on their expensive models. Currently, VR-technologies are being used to perform training at various stages of the operation and life cycle of nuclear power plants [2]. These include:

- Maintenance in urban environments;
- Control room operator training;
- Orientations within the nuclear plant;
- Reimbursement for decommissioning;
- Fuel handling;
- Emergency Management.

The agency carries out verification activities at more than 900 facilities worldwide, conducting approximately 2,200 inspections annually. Inspectors typically travel up to 100 days a year and, depending on the location, may be absent for up to four weeks. A wide range of nuclear sites are visited, including power plants, research reactors, and fuel fabrication and reprocessing facilities. They also need to learn how to use various types of equipment required on site.

The pandemic has had a significant impact on the ability to conduct on-site inspections. Transportation and internal constraints made it difficult for examiners to operate and increased the cost of examinations. Between March 1 and November 30, 2020, inspectors spent a total of 1,884 hours in quarantine. For the first time in its history, the Agency contracted for charter flights to shuttle inspectors and technical staff to and from inspection sites. The cost of these activities totalled €3.93 million for the transportation of 200 inspectors to 10 inspection sites. During this period, 1,680 inspections were carried out for a total of 15,500 days. Due to the pandemic, many planned maintenance activities had to be postponed.

Continuous retraining of existing professionals is also required to ensure that theoretical and practical skills remain relevant throughout their tenure. The Agency's Safeguards Course (ICAS) is a preparatory training

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program on safeguards and inspection activities that takes approximately 10 weeks, including theoretical training and practical exercises, as new inspectors come to the Agency with different levels of education and professional qualifications. Once the course is completed, future inspectors are assigned to sites. It is this part of the training that, due to Covid-19 constraints, could not be completed to the maximum extent possible. Within one or two years, inspectors are required to attend supplemental courses that expand their understanding of nondestructive analysis (NDA) techniques and inspection activities undertaken at more complex facilities. Due to potential transportation constraints, moving to a hybrid-training format is becoming the most appealing [2].

New training methods, such as the use of digital learning tools utilizing virtual reality (VR) technologies, have several advantages. It is possible to deploy practical working test scenarios as virtual reality technologies provide a high degree of detail and visualization. Virtual environments also offer a number of benefits such as cost and risk reduction. Therefore, it is crucial to create tools that take into account cognitive task analysis (CTA) methods and techniques. This methodology focuses on the cognitive aspects of the specialist's interaction with technical systems, in addition enabling, through the combination of cognitive analysis and cognitive synthesis, to identify additional aspects of equipment operation, monitoring personnel reactions to modifications of system objects [3]. This will help safeguard professionals with dynamic adaptation problem to maintain the efficiency of the organization at a sufficient level of performance.

II. Virtual Reality Simulator Concept

Virtual reality training is an immersive experience that recreates real-world conditions and simulates operational tasks. It provides on-the-job training to employees in a safe environment where they can virtually practice their learning. In turn, a VR-training simulator is a combination of modeling a physical object in a virtual environment and a scenario of interaction with it. In this case, a virtual reality training simulator provides real-time, interoperative and fully immersive artificial space where different engagement scenarios can be practiced and visualized.

VR-simulator is a software and hardware complex consisting of:

- Hardware – VR-helmets from one of the key manufacturers (Oculus, HTC Vive, Samsung, etc.);
- Interactive content - a digital environment created by rendering and programming a fictional or real space. Within it, the user can navigate and interact with virtual objects.

A virtual reality training simulator may have several scenarios for the user, which can be updated and generated depending on the consumer's goals and objectives. The software part is responsible for what set of features for interacting with the immersive environment will be included in the virtual training system.

3D-models and objects represent the internal environment. They can be visualized in one of the following 3D-modeling software for further export to virtual reality:

- Blender;
- AutoCAD;
- Maximum 3DS;
- SolidWorks and many others.

The main requirement is the format of the visualized 3D-model, which can then be exported to virtual reality. Some of the most popular formats are STL, STEP, OBJ, FBX and DAE. They are widely used in various applications ranging from video game animation to additive manufacturing.

III. Experience Of NRNU MEPhI's Digital Platform

In the framework of the educational environment of the Faculty of the Higher Engineering School of MEPhI, a special VR-laboratory was created, which serves as a basis for the establishment of a comprehensive Digital Platform [4,5]. Within 3 years, students and professors of the Faculty studied the possibilities of application of virtual reality technologies for implementation of educational programs for training and advanced courses for nuclear industry personnel in the Russian Federation.

The project on creation of a digital twin of the MEPhI Research Reactor started its digitization using Autodesk Revit software. As a result, the first and second circuits of the research facility with relevant equipment and structural elements, as well as horizontal channels and instrumentation were transferred into the model.

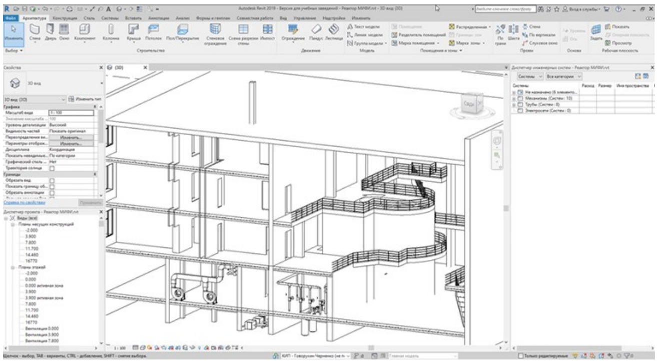

Fig. 1 – Digital model of the NRNU MEPhI research reactor in Autodesk Revit.

The experience was adopted for the development of an integrated simulator project for virtual reality training. A study of possible software options for operating with finalized models of physical objects was performed. The virtual reality simulator was developed using Russian VR Concept software, SteamVR and an additional C++ application. To develop the simulator, both built-in functions of VR Concept and functions written in the C ++ programming language were used to extend the functionality and simplify and accelerate the development of new VR-simulators. The data exchange between the C ++ application and the VR-Concept is accomplished through the UDP-port and is represented by an array with an index, number of an object in the scene, which returns or replicates a value (the second element of the array) in real time. SteamVR is used as a driver, namely it transmits the position of controllers, virtual reality helmet and other related behaviors [5]. The key advantage of this software package is the ability to quickly transfer CAD-models to virtual reality, without additional visualizations, with a fully constructed tree of model objects. However, a minor disadvantage has been identified, namely, the graphic images in the studied prototype simulator are of lower quality than analogs made with software based on the Unity or the Unreal kernel.

Fig. 2 – Digital model of the NRNU MEPhI research reactor in the virtual reality framework.

A virtual reality training simulator with visualization of the assembly/disassembly scenario and display of the engineer's statistics in virtual reality during the training process with text and audio prompts was developed using the example of a controlling disc valve. The control disk valve was created specifically for nuclear power plants, as control valves of traditional designs did not meet the requirements of modern process control equipment. The regulating disk valve is capable of ensuring high-quality operation of automatic control systems (ACS) in stationary and variable modes of power unit operation [6].

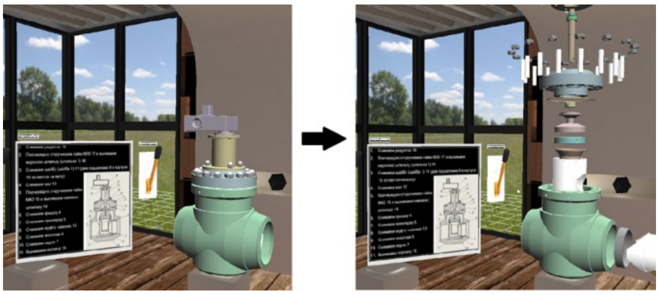

Fig. 3 – Control disk valve in the VR-simulator.

Preliminary testing was conducted, which included giving the laboratory staff the opportunity to experience the virtual environment in person. The need for a training facility for new users was identified because it was difficult for an individual who had never used a virtual reality helmet to adjust to a new environment. Due to this necessity, a training facility for new users was developed to overcome the barrier of transitioning into virtual reality. The virtual reality training facility consists of three scenes, each of which describes the process of human interaction with objects in virtual reality, navigation through it, and also describes the built-in VR Concept functionality needed in the training process: measuring the distance between 2 points, object diameter, making required notes, sketching inside the virtual environment, and assembly/disassembly animation. In addition to the mentioned above, the application written in C ++ was able to provide the development of simulations for assembly / disassembly of the model in the briefest time of 2-3 weeks with a limit of 100 parts in the model.

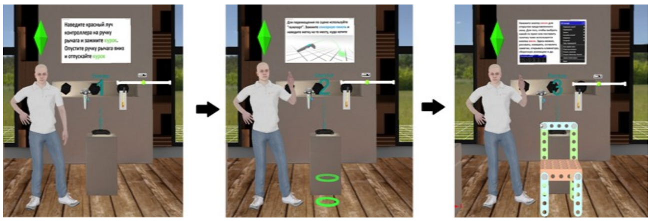

Fig. 4 – Digital model of the NRNU MEPhI research reactor in the virtual reality framework.

Follow-up tests were conducted with students from the Higher Engineering School who had not previously interacted with the VR-simulator. It was easier for new users to adapt to the virtual environment if there was a preliminary tutorial, which on average takes about 5 minutes. The availability of hints was also augmented to provide step-by-step assistance in controlling the digital model in the virtual reality simulator.

VR Concept's built-in features allow multiple people to be in a virtual meeting space at the same time by simply connecting to a shared server. In our study, a single personal computer was used to validate this capability. The testers were able to perform all necessary actions together without being physically present in the testing room.

Users mentioned that this learning experience increased their interest in both studying and exploring the possibilities of working in a virtual environment. However, it is worth mentioning that staying in virtual reality goggles for long periods of time caused motion sickness. Research conducted on the use of VR-devices also indicates a negligible impact on the users' vision. One of the most common is the problem with focusing at long distances after a long session of using a VR-helmet. These aspects are certainly the main obstacles to fully transition the learning process into a virtual reality environment. Testers of the virtual reality simulator also noted that being in virtual reality caused them stiffness of movement due to initial disorientation in space, they found it difficult to determine the scale of the room in the virtual reality simulator, and anxiety levels increased due to not understanding their own position in the physical test space. This aspect was debilitated in subsequent attempts to interact with the training simulator.

IV. Utilized Stack Of Technologies

The virtual reality training simulator architecture is presented as a virtual prototyping tool for the virtual reality framework and an auxiliary module written in C ++. The VR concept uses a custom SimulationManager plugin to interact with an external C ++ application. This interaction is done using a plugin from the vrcSimulationPlugins block. This work uses the concept of virtual reality-0.21-MShaposhnikov-simulation-rotation.1-288-ru-win64. It is worth mentioning that during the plugin development the simulation capabilities are changed and the functionality is refined, which should be taken into account when implementing the developed software modules. The plugin works with the user datagram protocol (UDP) and is used for bidirectional interaction with external modules of the application written in the programming language C++.

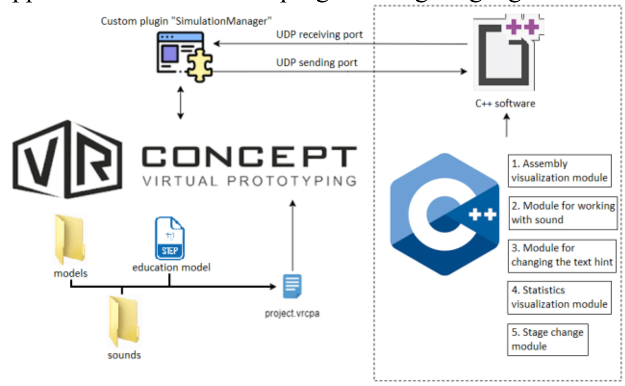

Fig. 5 – System component interaction architecture.

The development of the vrcpa-project is based on prepared models of the virtual scene (room, arrows, stands etc.) necessary for its formation, a set of audio files for subsequent playback in headphones or other helmet device and the CAD-model itself, which will be interacted with in virtual reality.

The bidirectional interaction between the external C++ application and the virtual reality framework is synchronized with transferred values for the simulation, as the generated packets must fully describe conditions at any point in time. The development of external modules to synchronize the custom SimulationManager plug-in with the virtual reality framework was done in constant interaction with the software developers, allowing the necessary functionality to be quickly added to achieve the desired goal. VR Concept communicates with external C++ application modules via UDP packets. In order to send the data correctly, an array was generated and populated with an index containing the parameters for the simulation. This framework involves sending the parameters of all simulation values, i.e. the state of the conceptual virtual reality scene combined with data received from external modules. In order for the SimulationManager to properly handle datagrams, it is necessary to interpret bytes as packed binary data, which is to process binary data stored in files or received from network connections among other sources into format strings as a compact description of the location of structures. This process is one of the important steps of interaction.

V. Results Obtained

The prepared simulator was tested on the site of the VR-laboratory of the Higher Engineering School of MEPhI. During the year the team of students, most of whom participated in the teamwork remotely, performed laboratory works in the virtual reality environment. Despite the fact that the recreated simulation of the research reactor components does not fully convey the realism of the picture, the students successfully mastered the proposed course and gained a profound understanding of the key mechanisms of the nuclear plant, as well as the interaction processes of the examined equipment.

This type of training is gaining momentum as it allows staff and students from around the world to fully recreate realistic interactions within the nuclear infrastructure and with each other. Virtual reality technologies are already being actively implemented at production facilities to train personnel to work at nuclear power plants. The developed VR-simulator prototype is planned to be completed, after which it will be tested and piloted as part of the professional training of maintenance personnel at JSC Atomenergoremont, a subsidiary of Rosatom State Corporation, which is the general contractor for the maintenance and repair of NPP equipment [8].

The results of the study were also presented in the form of a report at the International Atomic Energy Agency's international conference "Symposium on International Safeguards: Reflecting on the Past and Anticipating the Future" in November 2022.

VI. Conclusion

With the help of similar virtual reality simulators, authentic nuclear facilities where IAEA inspections are conducted can be digitized. Trainees will be able to assess the scale and operating conditions of existing facilities, familiarize themselves with the location of key infrastructure and the positioning of operating equipment. The process of mastering inspection tools, namely testing the detector interactions, can be conducted, sampling and sealing scenarios can be simulated, and basic scenarios for on-site inspections and non-destructive examinations can be developed.

Workplaces and tasks can be reproduced in a realistic virtual space where employees can receive hands-on training, but in a safe atmosphere. This means they can commit risk-free mistakes and refine their skills in the field. Our research confirms that today's software capabilities make it possible to recreate a complete training platform in virtual reality.

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