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Development of a virtual analogue of uranium-graphite subcritical assembly and visualization of the neutron flux distribution in virtual reality

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Abstract

The article describes the new software product developed at MEPhI. It represents a virtual reality simulation of an experiment on a subcritical uranium-graphite assembly. This practical work plays an important role in the training of young specialists studying the physics of nuclear reactors. However not all students have access to real experimental facilities, this fact makes it necessary to complement real experiment with simulation in virtual reality that allows to accurately reproduce the actions that the student performs during the real practical work. This approach let to increase the efficiency of the educational process and even expand the capabilities of real experimental assembly by visualizing physical processes during its operation.

Keywords: Virtual reality; Nuclear reactor physics; Simulation; Education

1. Introduction

Virtual reality (VR) is an actively developing technology that makes it possible to experience the virtual world created by the developer. As a rule, a special helmet is using to observe the virtual world and controllers to interact

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with it. The development of virtual reality technology systems began in the 1960s [1]. Interest in them periodically arose but they did not become widespread because of technical imperfection. However, thanks to the increased computing capabilities of computers and advanced computer graphics technologies it has become possible to develop truly believable simulations. In addition, it has become quite affordable, because a simple VR application can be run on most smartphones.

1.1. VR technologies in training and education

Initially, virtual reality technologies were developed for the entertainment industry, but the opportunities offered by VR attracted specialists from other fields, who began to actively use VR technologies to solve their problems. First of all, VR technologies became in demand in the field of training highly qualified specialists. For example, special simulators were developed to train surgeons that simulate laproscopic operations [2]. This simulator is designed to train future surgeons and to improve practical surgeon skills. There are also developments that should improve the perception of the school physics course, due to the VR visualization of real experiments [3]. According to the developers, the use of such programs should improve students' abstract thinking, as well as help in understanding the phenomena that cannot be perceived with the help of basic human senses. For such purposes, VR is also used in science. In this area VR technology is usually used to illustrate objects that are difficult to depict on a plane drawings or to visualize phenomena that are even difficult to imagine. For example, at the Bavarian Academy of Sciences the set of open source virtual reality applications has been developed. They can be used to visualize results of simulation of various types of chemical reactions [4].

1.2. VR technologies in nuclear industry

The use of virtual reality is also found in the field of nuclear energy. For example, General Electric (GE) uses the VR to train their nuclear engineers [5]. They use an application that provides 3D models of steam turbines rotating a generator inside a nuclear power plant. Animations of these objects help young engineers to understand how to install and disassemble turbines. Another single example of usage of virtual reality for training in the nuclear industry is the VERL (Virtual Education and Research Lab) project [6] developed by the Department of Nuclear, Plasma, and Radiological Engineering at the University of Illinois. The developers precisely recreated the TRIGA (Training, Research, Isotopes, General Atomics) research reactor disassembled in 2004 and the machine room in which it was located with the accuracy up to emergency exits and toilets. This allows the use of an already inaccessible installation to continue student teaching. The application allows demonstrating to students how dosimetric measurements are carried out at a nuclear facility in a safe environment. The user gets a virtual Geiger counter to make dosimetric measurements of a pre-calculated radioactive field around the reactor. The aim of the developed simulation is to teach students three key concepts of nuclear safety: time, distance, protection.

1.3. Background to this work

The described work is a VR simulation of a subcritical experiment on a uranium-graphite subcritical assembly that is a development of a two-dimensional application developed at the MEPhI previously (it was actively used for teaching of students [7]). The need to create such a program arose because of the difficulties associated with conducting a real experiment. Firstly, there are not so many such assemblies to allow all students studying nuclear reactor physics perform real experiment. Secondary, there are technical difficulties with a real installation. For example, due to the increased humidity of the air, graphite has become damp and such properties as the neutron moderator have changed. It will not allow to obtain the correct result. But despite this, students must complete the experiment according to the schedule of studies.

2. Uranium-graphite subcritical assembly and the laboratory work description

The experimental facility for determining of the material parameter of the uranium-graphite lattice located at National Research Nuclear University MEPhI (Moscow Engineering Physics Institute) is a prototype of the created virtual analogue. The facility consists of graphite blocks with inserted fuel rods of the natural uranium. Also, uranium-graphite subcritical assembly has additional holes for insertion of the neutron source and the neutron radiation detector.

The geometric description and photograph of the experimental assembly are shown in Figure 1.

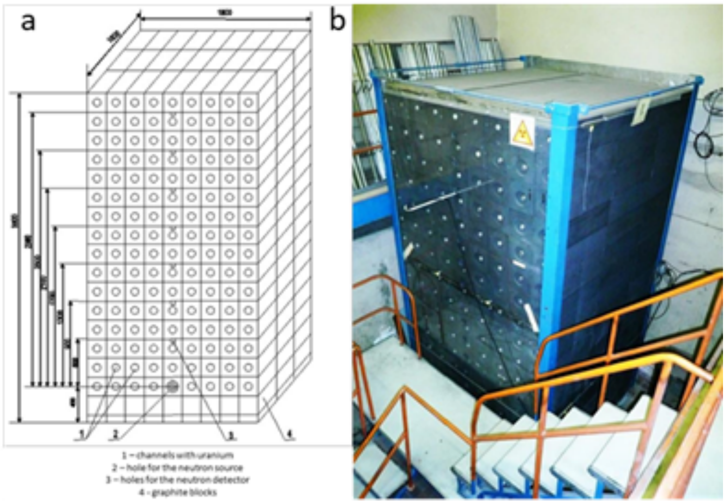

Fig. 1. The scheme (a) and the general view (b) of the uranium-graphite subcritical assembly.

In the framework of the laboratory work "Experimental determination of the material parameter of a uranium-graphite lattice" MEPhI students are trained in the experimental determination of the material parameter of the medium [8, 9]. The laboratory process is following:

- The measure of an axial distribution of the neutron background;
- The measure of an axial distribution of the neutrons when a neutron source is inserted into the assembly;
- The measure of an axial distribution of the neutrons when a neutron source is inserted into the assembly and when a cadmium cap covers the neutron detector;
- The processing of the measured data and calculation of the material parameter of the medium.

3. Previous versions of the virtual analog and a neutron flux distribution modeling

The purpose of the lab is to determine the multiply properties of the material environment, consisting of metal uranium cylinders (natural uranium) located in the nodes of the square lattice with a pitch of 20 centimeters and graphite. The criterion of the multiply properties of the material environment is a material parameter. If it smaller than zero, this material environment isn't suitable for nuclear reactors construction. For the determination of this criterion it is necessary to measure the axial distribution of the neutron flux in the middle of the subcritical assembly. The previous version of the virtual analogue of the subcritical assembly is a 2D program, which allows you to change the square lattice pitch and the percentage of uranium enrichment (which is impossible in a real subcritical assembly) and measure the axial distribution of the neutron flux in the middle of the subcritical assembly. The values of the neutron flux, which are displayed to the user as the measurement result both in the previous version of the virtual analogue of the subcritical assembly and in the modern version, were obtained by modeling the subcritical assembly in the MCU program[10]. The MCU program allows you to simulate the processes of radiation transport in various materials using the Monte Carlo method and to determine some of the functionals of neutron fields, which is especially important in the physics of nuclear reactors. To calculate the distribution of the neutron flux, the geometry of the subcritical assembly was reproduced (using the combinatorial approach and geometric primitives) and the nuclear densities of the assembly materials were specified. A source of monoenergetic neutrons with an energy of 1 MeV was also set, simulating a real neutron source used in the experiment. Also simplified model of boron neutron detector has been used to allow to simulate the impact of the neutron field to the real detector used for measurements.

4. General structure of project

The project development consists of several processes:

- 3D model development;
- Calculation of neutron fields;
- Development of algorithms for interacting with interactive objects in Unreal Engine environment.

At the beginning CAD models were developed in order to accurately represent the geometric features of the assembly. Then these models were optimized and polygonised for correct display in the game engine. For user interaction with the virtual environment we developed scripts in the game engine. The development process is presented in Figure 2.

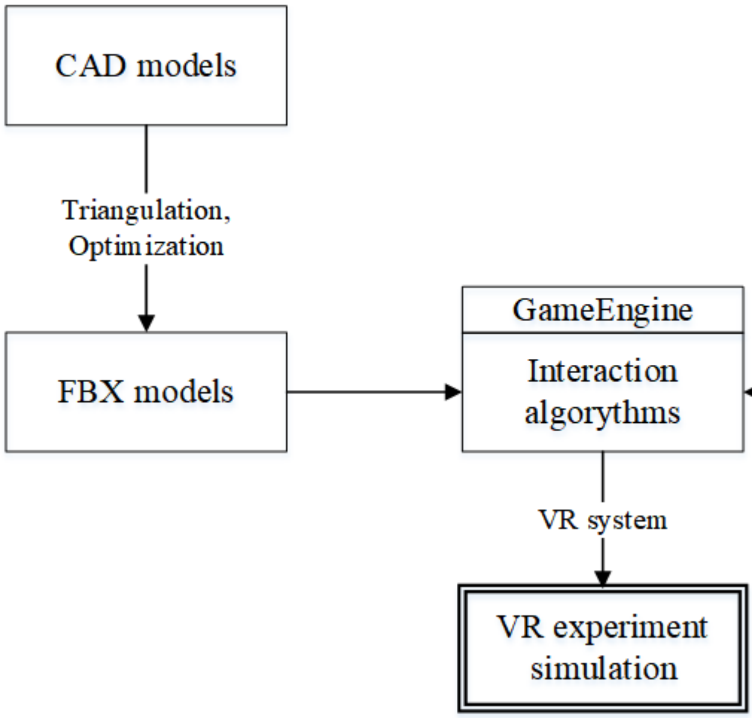

Fig. 2. Project Development Scheme.

4.1. Development of 3D models

Three-dimensional models of subcritical assembly, rooms and environment objects were created in the 3ds MAX [11]. The engineering and construction drawings of real installation were used to make representation more realistic. The triangulated models were imported into the game engine and then assigned with texture maps. Interactive subjects in virtual lab are the detector, the counting device and the neutron source.

4.2. Development of interaction with virtual objects

To develop user interaction interface with objects in virtual reality the Unreal Engine 4 [12] game engine was used. The presence of a plug-in for interacting with SteamVR in Unreal Engine, as well as built-in templates, significantly simplified the development process and allowed us to concentrate on the main problem: the accuracy of experiment simulation. Pre-calculated values of neutron flux in the corresponding measuring channels are used for interactive measurements. In order to make results variable we used a normal distributed error. The measurement process repeats all the actions that the user usually perform during a real experiment. The user can pick up the following items: detector, neutron source, cadmium shield. He can interact with them: place the detector in the measuring channel, put the cadmium cover on the detector, press the buttons on the neutron counter. In addition, the visualization of neutron field (Figure 3) in the assembly was added by means of the particle system of the UE. Such features increase the learning potential of the virtual laboratory work, helping students better understand neutron physics.

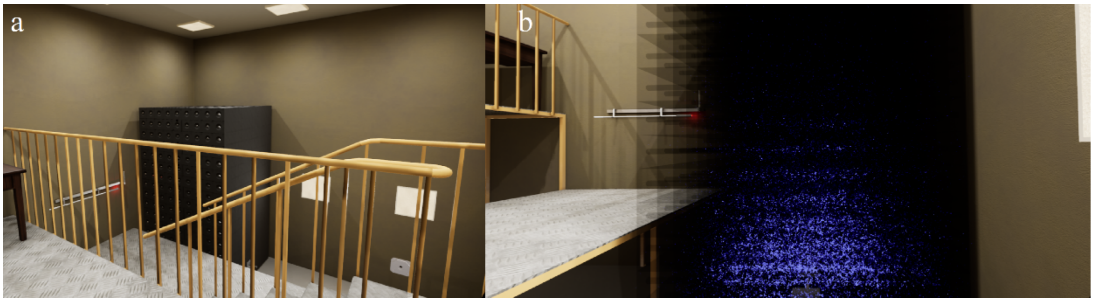

Fig. 3. (a) General view of the assembly, (b) Visualization of neutron fluxes.

5. Results and conclusion

The developed virtual laboratory work allows to ensure accessibility to the subcritical experiment. The possibility to conduct the experiment does not depend now on the state of the real assembly. The features of virtual reality widen the student experience from the practical work.

At different stages of development, this application was tested by students who already performed this work at a real assembly as well as by those who see this installation for the first time. Thanks to this approach, the process of debugging has been optimized as much as possible. To introduce laboratory work into the educational process, methodological materials have been prepared. They contain the theoretical justification of the experiment, and describe the process of its execution in virtual reality.

The use of such approach in creation of laboratory works of students opens up new possibilities for explanation of complex and sometimes dangerous experiments. Now any person, even without the necessary training, can practice in virtual reality before performing a real work.

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