Emera, a virtual reality radiation protection training platform

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Introduction

Radiation protection defines all the measures taken to ensure the protection of humans and their environment against the harmful effects of ionising radiation. It applies in many fields such as the control of nuclear installations, medical applications for imaging and therapy or the management of radioactive waste. Whatever the field concerned, the initial and ongoing training of personnel in radiation protection is a fundamental element for the safety of the public and workers.

In this context, the EMERA project (Experimental Platform for Radioactivity Measurements), carried out in collaboration between the Physics & Engineering Faculty of the University of Strasbourg and the IGG team (Computer Graphics and Geometry) of the Icube laboratory, aims to develop a virtual reality training tool for radiation protection. This tool should enable users to better understand the various situations of exposure to ionising radiation that they may encounter within the course of their professional activity in order to improve their practices. The tool is also intended to be used in the context of the "Nuclear Techniques and Radiation Protection" degree offered at the University of Strasbourg, in order to provide students with a risk-free means of training in the various radiation protection professions. Several scenarios have been implemented in the medical field (interventional radiology) and the industrial field (control of radioactive contamination). For each scenario, the user has to carry out several missions in a radiation exposure situation, while limiting the dose received as much as possible (ALARA principle). The user is provided with protective equipment and measurement systems that can be selected according to the situations encountered. The missions can be carried out with several levels of difficulty, based on the possibility of visualising or not the radiation field (dose rate) in 3 dimensions. The development of this tool was thus an opportunity to study different options for representing a radiation field in virtual reality, with the aim of seeking the visualisation solution best suited to the perception of risk in radiation protection. Our software was developed using the Unreal Engine game engine for use with Oculus Quest 2 virtual reality headsets.

Two areas: interventional radiology and radioactive contamination control

Figure 1. Arm rotation in the interventional radiology scenario

A first set of scenarios takes place in an interventional radiology room (use of radiology to enable diagnostic and therapeutic procedures). Radiation is emitted by an X-ray generator placed in the centre of the room, which can be moved in space by rotating the mechanical C-arm (Figure 1). A series of exercises, mainly based on the positioning of the staff in the room during the procedure, are proposed with different visualisation methods.

These exercises allow the user to better visualise the spatial distribution of radiation in the room as a function of several adjustable parameters such as beam energy or intensity. By becoming familiar with this radiation environment, the user should be able to optimise their positioning and movements in order to reduce the total dose received during the procedure. The tool allows the user to know at the end of the exercise the dose received by the different parts of his body (head, trunk, arms, hands, legs), and to visualise the evolution of the doses received over time.

Figure 2. Example of perimeter delimitation in the industrial scenario

The second set of scenarios takes place in an industrial environment. Radiations are emitted by one or more sources of radioactive contamination hidden in the room (point sources, liquid contamination residues,). Using a dose rate measurement system (different types of detectors are proposed to the user, more or less relevant according to the type of contamination) and a spray paint can, the user has to delimit a safety perimeter around each identified contamination zone (Figure 2).

Once the perimeter(s) have been delimited, the radiation field is displayed and the user is evaluated according to the dose received by the different parts of his body and the precision of the delimited zone. This exercise allows users to be trained and evaluated in contamination control procedures (choice of measurement system, zone delimitation, risk taking, etc.). The exercises to be carried out allow to choose different types of gamma and/or beta emitting radionuclides (^{137}Cs, ^{60}Co, ^{241}Am, ^{18}F, ^{131}I, etc.) and different activity levels (in Becquerel).

3D dose rate mapping

3D dose rate maps (µSv/h or equivalent) have been pre-calculated from a Monte Carlo modelling of the different scenarios. The modelling is carried out using the GATE software [1], based on the Geant4 radiation-matter interaction calculation code developed by CERN. The rooms in which the exercises take place are subdivided into voxels of varying resolution (currently 10x10x10 cm^3), and the dose rate value corresponding to each voxel is calculated according to the various scenarios. By setting the adjustable parameters (energy, intensity, radionuclides, activity ...) at the beginning or during the exercise, the corresponding dose rate map is selected from the database. The user's movement (position, time) then allows the calculation of the integrated dose received by each body part. In interventional radiology, this database contains, for example, maps calculated for several beam intensities, radiation energies (between 50 and 150 kV), positions of the C-arm and for certain specific cases such as the use of a lead shield at the level of the legs or the presence of a doctor in the radiation field (shielding).

Radiation field display methods

In order to display the pre-calculated 3D radiation field mapping, several visualisation methods have been developed and evaluated. The visualisation of the radiation field (and the relative perception of the user) is a very important element for a tool intended for radiation protection training. A first method, inspired by the work of Takeshi Takata [2], consists of discretising the 3D space and displaying coloured transparent spheres for each portion of the space (Figure 4.1). A second method uses the surface nets algorithm [3] to construct transparent iso-surfaces at different radiation field intensity thresholds (Figure 4.2).

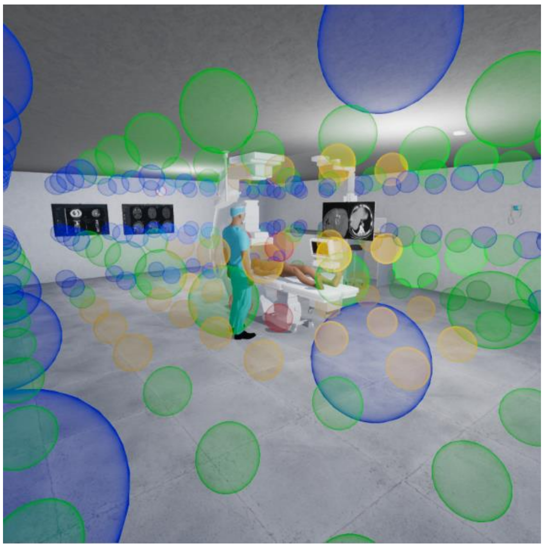

Figure 4.1. Visualisation by transparent spheres

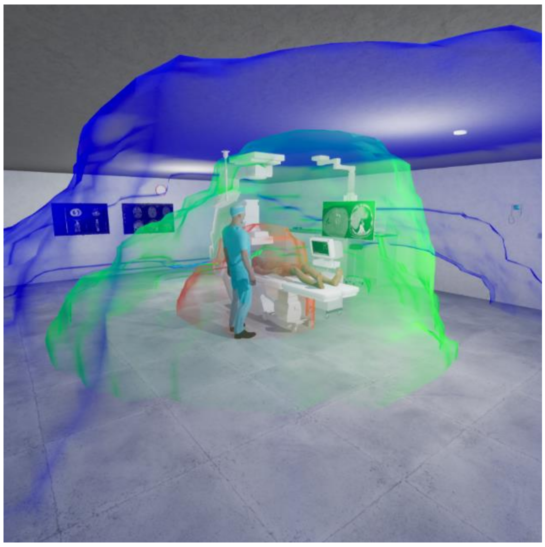

Figure 4.2. Visualisation by iso-surfaces

A third method, inspired by the work of Michael N. Louka [4], displays a histogram on the ground where the height of a stick represents the average intensity in the column of that stick, a variant of this method has been developed by replacing the histogram with a mesh (Figure 4.3). Finally, a fourth method, inspired by Tessa E. Klunder [5] displays a large number of particles whose random position is weighted by the intensity of the radiation field, the density of particles in a given space thus representing the intensity of the field (Figure 4.4).

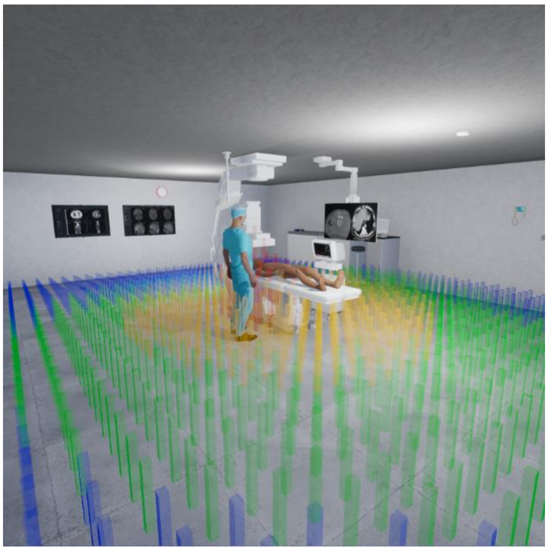

Figure 4.3. Visualisation by histogram

Figure 4.4. Dynamic particle visualization

Dose calculations

In the different scenarios, the user has one or more missions to accomplish and his behaviour can be observed by a teacher in multi-user mode. An avatar reproduces his movements in the virtual environment by inverse kinematics. His path, dose rates and cumulative dose received are recorded and can then be analysed. To calculate the doses received by the different parts of the body, an approximation of their geometry is considered in relation to the 3D dose rate map (intersection between the limb or organ and the voxel(s) of the map). A miniature representation of the user's avatar can also be displayed on his wrist (Figure 6.1). It shows for each part of the body the real time dose rate and the cumulative dose received since the beginning of the sequence.

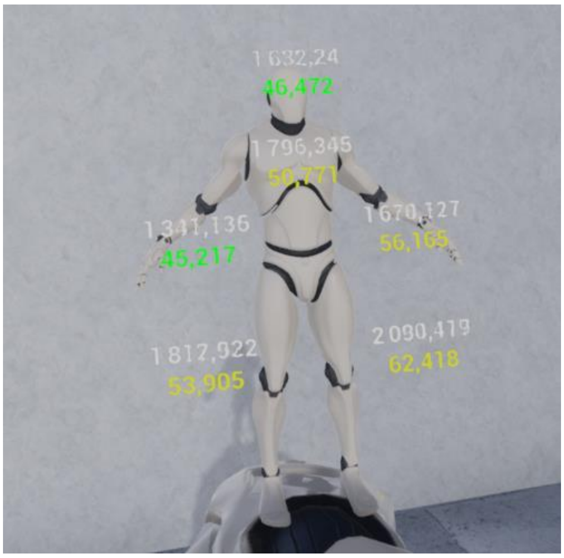

Figure 6.1. Dose received by the different parts of the body

Figure 6.2. Protective equipment

Some scenarios also allow the user to select the protective equipment to be worn in the preparation room (Figure 6.2). This equipment is taken into account in the calculation of the dose received in the form of a reduction coefficient. The user will thus be able to see the reduction in the dose received with and without the use of the appropriate equipment.

Conclusion

The EMERA virtual reality radiation protection training platform offers users (staff, students) the possibility of experimenting different exposure situations, and thus optimising their practices, without taking any risks. This platform will be used for the next academic year in the framework of two training courses on radiation protection in initial and continuing education. The users will be students/staff in the medical field (doctors, technicians, nurses) for interventional radiology, and students/workers in radioactive contamination control organisations for the industrial field. The first user tests carried out have validated both the field visualisation methods and the different scenarios proposed in the current version of the tool. We are waiting for the feedback from the next training sessions to improve the user experience and to propose new scenarios or even for new fields of application.

A video of the application can be accessed here: https://igg.icube.unistra.fr/index.php/Emera

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