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An Approach to Calculate and Visualize Intraoperative Scattered Radiation Exposure

Markus WAGNER [a,1], Christopher DUWENKAMP [a], Klaus DRESING [b],
Oliver J. BOTT [c]
[a] *Peter L. Reichertz Institute for Medical Informatics, TU Braunschweig and Hannover Medical School, Braunschweig, Germany*
[b] *Department of Trauma Surgery, Plastic and Reconstructive Surgery, Georg-August-University, Goettingen, Germany*
[c] *Department for Information and Communication, Faculty III, University of Applied Sciences and Arts, Hannover, Germany*

Abstract. During the intraoperative radiograph generation process with mobile image intensifier systems (C-arm) most of the radiation exposure for patient, surgeon and operation room personal is caused by scattered radiation. The intensity and propagation of scattered radiation depend on different parameters, e.g. the intensity of the primary radiation, and the positioning of the mobile image intensifier. Exposure through scattered radiation can be minimized when all these parameters are adjusted correctly. Because radiation is potentially dangerous and could not be perceived by any human sense the current education on correct adjustment of a C-arm is designed very theoretical. This paper presents an approach of scattered radiation calculation and visualization embedded in a computer based training system for mobile image intensifier systems called virtX. With the help of this extension the virtX training system should enrich the current radiation protection training with visual and practical training aspects.

Keywords. scattered radiation, simulation, visualization, CBT, radiation protection, C-arm

1. Purpose

In the treatment of human and even animal trauma and emergency patients mobile image intensifier systems (C-arms) are essential tools. They are used to produce radiographs from every direction around the patient for controlling, documentation and monitoring purposes. This mobility of the X-ray apparatus is achieved by mounting the radiation source and the image intensifier on a metallic C-construction (see Figure 1) which can be moved and rotated around all three spatial dimensions. But this freedom in movement makes radiation shielding arrangements like on stationary X-ray devices very difficult or sometimes impossible. Furthermore the surgeon respectively the operation room personal (ORP) can not leave the operation theatre during the

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[1] Corresponding Author: Markus Wagner, Mühlenpfordtstr. 23, 38106 Braunschweig, Germany; Tel.: +49 (0) 531 391 2125; E-mail: markus.wagner@plri.de.

radiograph generation process whereby they are frequently exposed to radiation. Scattered radiation is emitted by the irradiated area of the patient every time a radiograph is generated and takes up the biggest amount of the exposure for ORP [1, 2]. Intensity and propagation of this radiation depends on the composition of the irradiated material and the intensity and direction of the primary beam [3]. Therefore the intensity and propagation of scattered radiation mainly depends on the positioning of the C-arm over the field of operation, the distance between patient and radiation source, radiological parameters, and the thickness and kind of the irradiated tissue. To minimize exposure through radiation and especially through scattered radiation for patient and everyone in the operation theatre, the ORP controlling the C-arm has to know how to position the mobile image intensifier correctly to get a meaningful radiograph for the current surgical situation with a minimum of scattered radiation. Furthermore the surgeon and everyone else in the operation theatre has to know how scattered radiation spreads from irradiated material so they can choose the safest stand during the radiograph generation process. This knowledge should be presented to ORP during courses on radiation avoidance. In Germany and other countries ORP have to visit these courses by law. But currently presentation and education of knowledge how scattered radiation can be diminished is done only in theoretical lectures due to the fact that training with real radiation is potentially dangerous, which makes it prohibitive, and that radiation itself could not be perceived by any human sense.

To improve education in these courses a simple prototypical visualization of the scattered radiation was integrated in the computer based training system (CBT) virtX. virtX (cf., [4–6]) offers exercise based training of correct C-arm adjustment with visual feedback through a digitally reconstructed radiograph (DRR) based on real CT-Datasets. C-arm adjustments can be trained by steering a virtual C-arm, patient and operation table in a 3D operation theatre scene with mouse and keyboard or by moving a tracked real C-arm and patient manikin which control their virtual pendants. The prototypically visualization of the scattered radiation in virtX consisted of a pulsating sphere whose center was defined by the point where the central beam of the image intensifier hits the patient (see Figure 1). The maximum expansion radius of the pulsating sphere should demonstrate the intensity of the scattered radiation and was affected by the distance between radiation source and patient, insertion of apertures and the tube voltage. This first version of the scattered radiation visualization was already positively evaluated based on questionnaires during a course for ORPs (cf., [5]). To visualize the physically correct propagation and intensity of the scattered radiation, which could not be achieved with the pulsating sphere, a new version of the scattered radiation visualization was developed and integrated in the virtX system. Aim of this paper is to describe this new visualization technique of the scattered radiation.

2. Methods

To calculate physically correct behavior of scattered radiation the GEANT4 toolkit in the version 4.8.2 [7] and CLHEP in the version 2.0.3.1 [8] were used. The GEANT4 (*GEometry ANd Tracking*) toolkit which was developed at CERN and written in C++ simulates the passage of particles through matter using Monte Carlo methods. During these calculations GEANT4 uses the *Class Library for High Energy Physics* (CLHEP) which is currently managed and hosted by the CERN too. In GEANT4 it is possible to construct detector geometries with all physical characteristics like shape, materials and electromagnetic field. Areas of these detector geometries can then be defined as sensitive detectors. These areas are sensitive for every kind of impacting photon or particle and they protocol all physical data of detected events (like direction and energy of the photon or particle, energy deposition, etc.). Furthermore primary generators can be created in the GEANT4 scenery. These generators emit from a fixed point a defined number of user specified particles or photons with a discrete energy and moving direction into the GEANT4 scene. In one run of a GEANT4 simulation a user defined number of primaries are emitted by the primary generators and the toolkit calculates the way of these particles or photons through the different objects and materials. After the run the user can extract information of particle and photon hits on the sensitive detectors. Thus one can gather information of radiation intensity on discrete points in space for the specified scene setup.

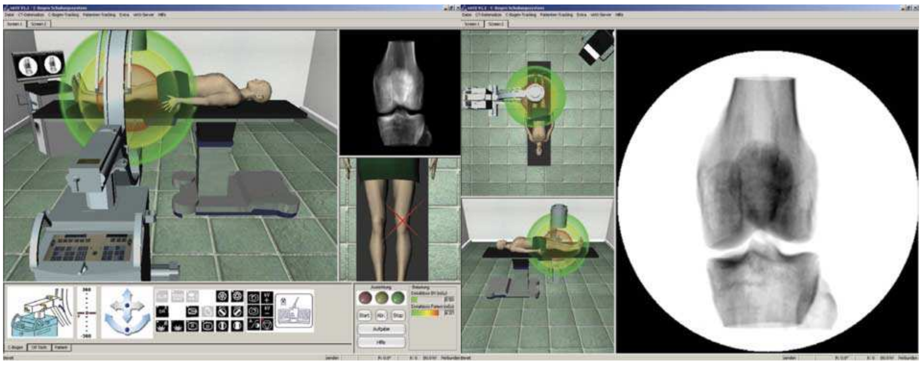

Figure 1. Graphical user interface of virtX with prototypical visualization of the scattered radiation

Because GEANT4 is designed to be used in a Linux environment and the CBT-system virtX is based on the Microsoft Foundation Classes (MFC) the GEANT4 toolkit was ported into the Integrated Development Environment (IDE) Visual Studio 2005.

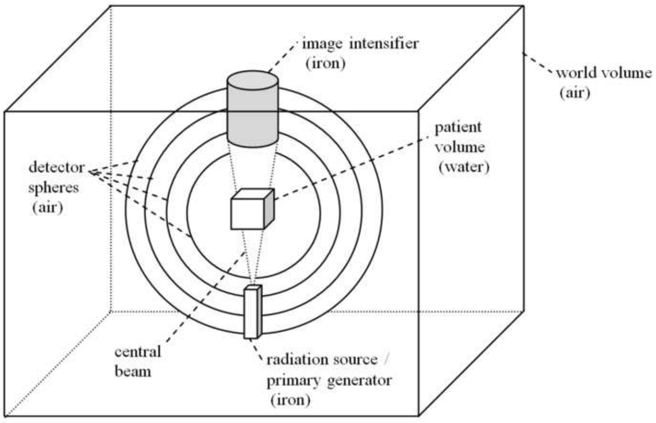

Figure 2. Schematic description of the detector geometry and the primary generator in GEANT4

After integrating GEANT4 in the virtX project a simple detector geometry depicting the current situation in the operation theatre was constructed using the toolkit (see Figure 2). First a world volume with the material “air” was created to represent the operation theatre. Inside this volume an iron cylinder and cube were added for the image intensifier and radiation source geometry. For simplicity and to decrease calculation time the irradiated volume of the virtual patient is represented as a water cube in the GEANT4 scene. Corresponding to the positioning of the virtual patient in relation to the virtual C-arm the water cube is positioned in the GEANT4 scenery. To model the primary beam of the mobile image intensifier a primary generator was inserted on the radiation source geometry. This generator produces a user defined number of gamma photons with an energy adjusted by the tube voltage parameter in the virtX system. The propagation direction of the gamma photons is set randomly in the area of the central beam of the mobile image intensifier (see the cone in Figure 2). Around this setting a number of interleaving detector spheres (DS) were created, each consisting of the material air to avoid interferences in the calculation. The DS act as a sensitive detector. Thus every photon hitting the surface of one of these spheres can be detected with its position and energy. By increasing the number of interleaving DS a more exact picture of the radiation propagation in the scenery can be drawn.

To visualize the calculation results of the GEANT4 toolkit a volume was inserted in the 3D operation theatre scene of the virtX system. The center of this volume is in-between the radiation source and the image intensifier of the 3D model of the C-arm and it performs the same rotations as the C-construction. For each photon hit on the DS in the GEANT4 scene the corresponding voxel in the volume in the virtX scene is colorized. The colors of the voxels depend on the measured photon energies: from green for low energy photons over orange to red for high energy photons. Figure 3 shows the visualization of the scattered radiation propagation for different C-arm, respectively operation table adjustments (simulation done with 5000 photons and 9 DS).

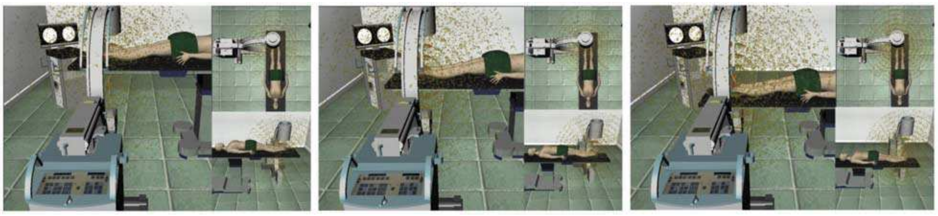

Figure 3. Visualization of the GEANT4 calculations in the 3D scene of the virtX system for different C-arm/table adjustments (5000 photons, 9 detector spheres)

3. Results

The main problem in calculating the physically correct behavior of scattered radiation for varying setups with Monte Carlo Methods is the calculation time. Because the visualization is planned to be used during training of C-arm adjustments the calculations are required to be in real time. To determine which number of DS and simulated photons produces a meaningful visualization in an acceptable time different setups were tested. On a standard PC (Intel Core2 Quad Q6700 CPU at 2.66 GHz, 3.5 GB RAM, Nvidia GeForce 8800 GT graphics board) the calculation times for 9 to 3 DS, 1,000 to 20,000 photons and a fixed C-arm and patient situation were measured (results see Table 1). By comparing the visualization results with isodose curves which were measured during the operation of a real C-arm it was found that the visualization of 5,000 to 10,000 photons with more than 7 DS already presents sufficient information to demonstrate the propagation of scattered radiation. Based on the calculation times a number of 9 DS and 5,000 photons were chosen as most adequate setup for the C-arm training purposes.

Table 1. Calculation times for the scattered radiation simulation for different numbers of detector spheres and simulated photons (DS = detector spheres)

Number of simulated photons	**Calculation time in seconds**						
	9 DS	**8 DS**	**7 DS**	**6 DS**	**5 DS**	**4 DS**	**3 DS**
1,000	2.7	2.5	2.5	2.4	2.3	2.2	2.2
2,000	3.4	3.2	2.9	2.7	2.5	2.5	2.4
3,000	4.2	3.8	3.5	3.1	2.8	2.8	2.7
5,000	**5.8**	5.2	4.6	4.0	3.5	3.4	3.3
10,000	9.8	8.6	7.3	6.1	5.1	4.9	4.7
15,000	13.8	11.9	10.0	8.2	6.7	6.4	6.0
20,000	17.8	15.3	12.7	10.3	8.4	7.9	7.3

4. Conclusions

With this new calculation and visualization concept integrated in virtX it is possible to demonstrate the behavior of scattered radiation for discrete points in the virtual environment and different C-arm adjustments with an acceptable calculation time. Based on results of a questionnaire based evaluation of virtX by surgeons and the comparison of the simulation with measured isodose curves of a real C-arm we can conclude, that despite the high abstraction of the patient via the water volume and the small number of simulated photons and DS the generated images seem to be appropriate for the intended education purposes. However a more intuitive visualization which depicts the radiation dose distribution around the irradiated area (isodosis curves) more realistically would be preferable. Furthermore it is desirable to consider the different densities of the irradiated materials (e.g., different types and thickness of tissue, operation table material) in the calculation. Further research is needed to develop a visualization method that takes the physical properties of all present objects into account and depicts the radiation exposure for every point in the virtual operation theatre in an acceptable calculation time.

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[7] GEANT4, GEANT4 worldwide collaboration of scientists and engineers, http://geant4.cern.ch/.

[8] CLHEP – A class Library for High Energy Physics, CERN, Geneva, http://www.cern.ch/clhep/.