Quality Assurance of Radiotherapy Treatment Using Scattered X-Ray

Computer Integrated Surgery II

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Tatiana Kashtanova and Samuel Ydenberg under the auspices of Dr. Xun Jia and Dr. Lin Su

Introduction

In this project, we implemented a quality assurance (QA) method for radiation therapy (RT) using scattered x-ray registration. First, using the gDPM simulation package, we obtained the position, momentum direction and energy of the photons scattered outside of a phantom after a MV x-ray beam passed through it. Then, using MATLAB, we collimated the scattered photons and registered them on a photon counting detector. Finally, we related the recorded detector signal to the delivered radiation dose and analyzed the method feasibility. The procedures were carried out on both homogeneous and heterogeneous phantoms.

QA in RT aims to ensure the precise and safe delivery of the prescribed radiotherapeutic dose to a patient. As there are many challenges involved into the process, there is a need for a method that verifies the delivered dose deposition externally and in real time while introducing no additional dose.

The Problem

During RT sessions, the greatest challenges in delivering the prescribed dose precisely come with patient mispositioning, organ movements, and anatomical morphological changes, all of which may result in tumor underdose and/or normal tissue overdose. The current solutions include image-guided radiation therapy and adaptive radiation therapy where physicians use imaging to detect deviations from the initial planning and make the corresponding adjustments. The disadvantage of these techniques is an extra low radiation dose to the patient which, when accumulated over time, may result in developing secondary malignancies.

The Solution

Scattered x-rays allow to infer the dose deposition in a medium externally, potentially in real time, while introducing no additional dose. The method was implemented using the system depicted in Fig. 1 which comprises two parts: 1) The simulation of a MV x-ray beam transport through a phantom and the registration of the photons in a scoring sphere (the gDPM); 2) The scattered photons' transfer from the scoring sphere to a photon counting detector and the relation of the detector signal to the delivered radiation dose (MATLAB).

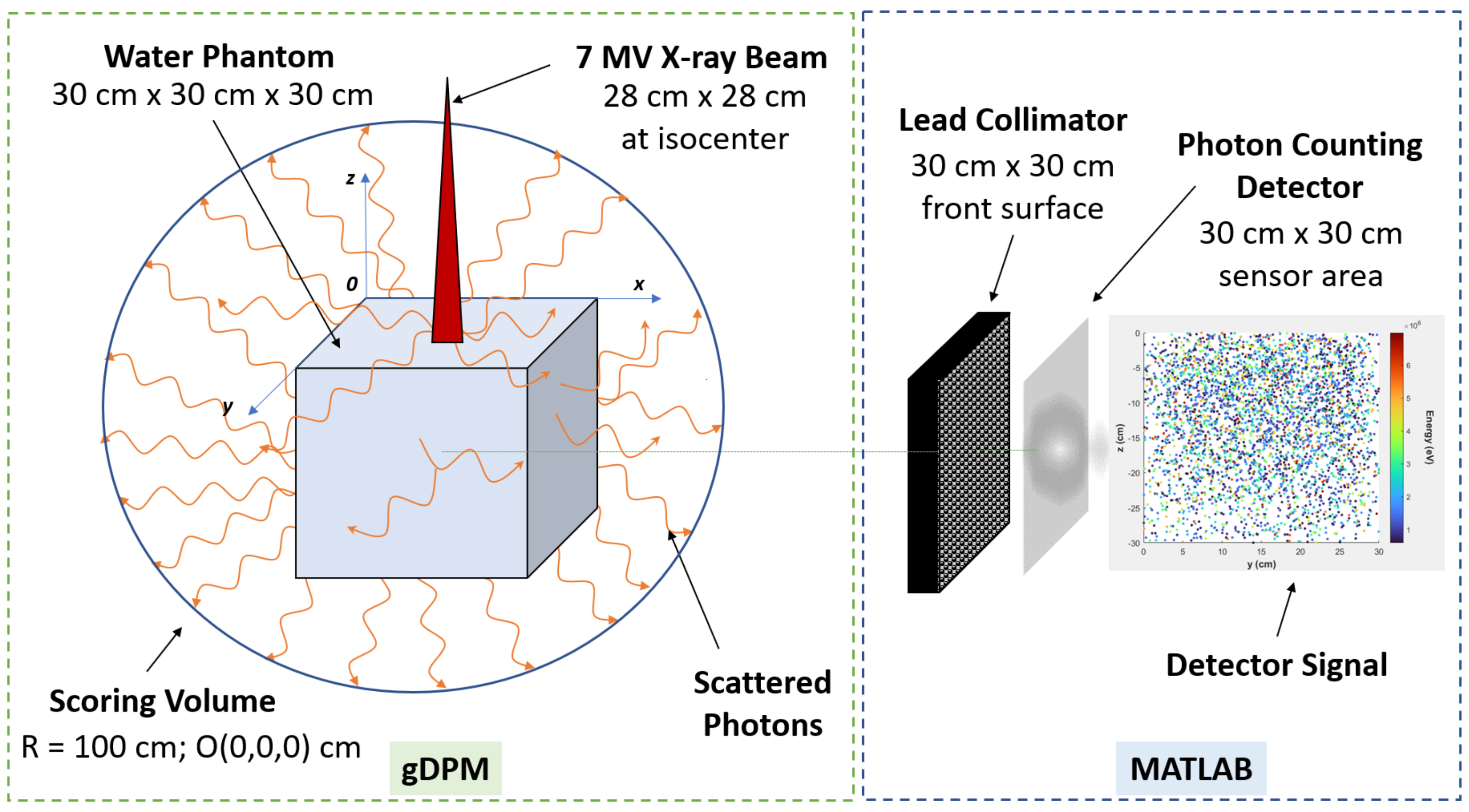

Fig. 1. System design

The procedures were carried out on homogeneous and heterogeneous phantoms. Thus, we considered two cube-shaped water phantoms with side lengths of 30 cm and 15 cm (the beam cross-sections at isocenter were 28 cm x 28 cm and 7 cm x 7 cm, respectively), and two cube-shaped heterogeneous phantoms with a side length of 30 cm and the beam cross-section of 28 cm x 28 cm at isocenter: one phantom consisted of water and bone (Fig. 2, left) and another one consisted of water, bone and air (Fig. 2, right).

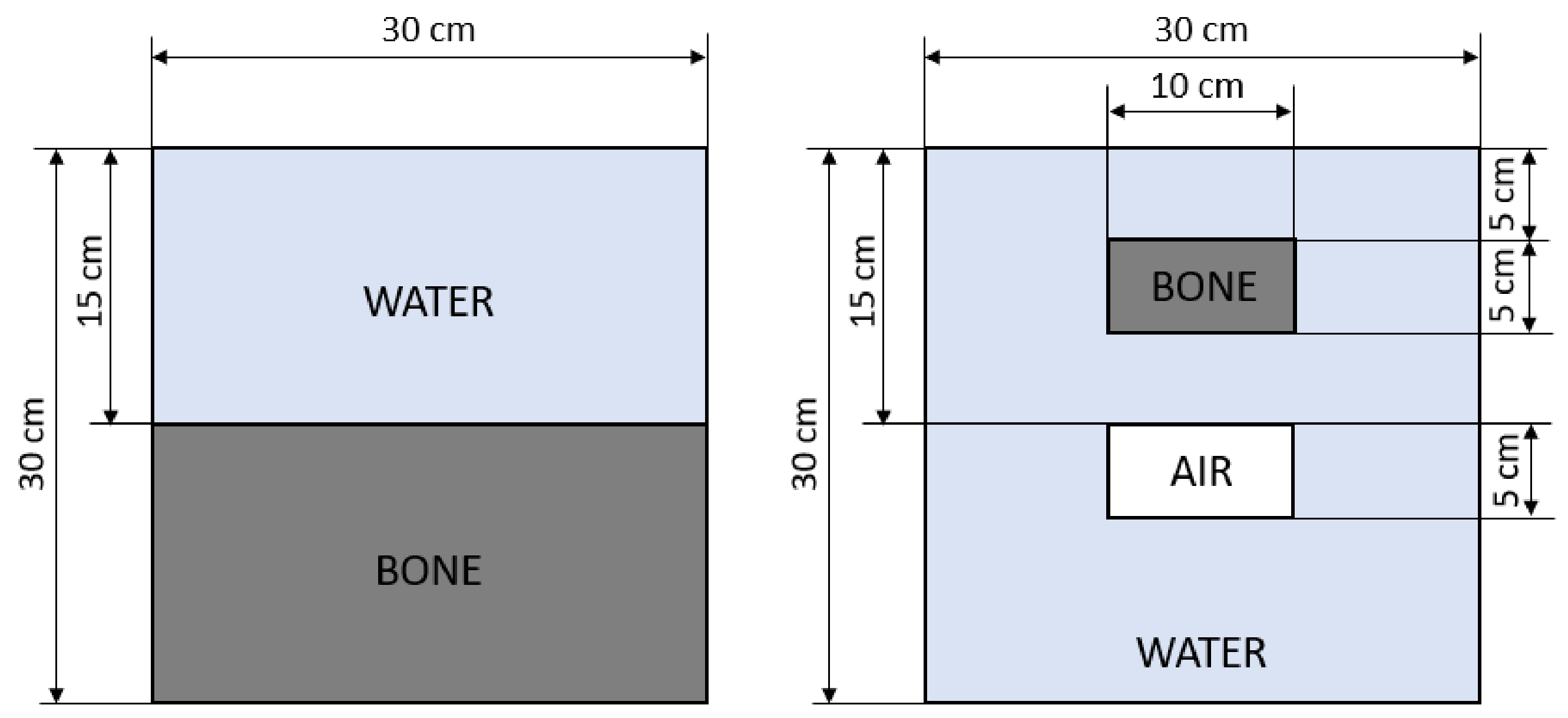

Fig. 2. Heterogeneous phantoms

Photon transfer from the scoring sphere to the detector was performed using a parametric representation of photon traveling trajectories. Then, the photons were collimated by either angular filtering or via interactions with a collimator. Next, they were subjected to an energy filtering. Here, the effect of six energy thresholds was explored: 100 − 1000 keV, 0 − 500 keV, 100 − 500 keV, 100 − 450 keV, 150 − 450 keV, and 200 − 450 keV. The system performance was assessed under four phantom-detector distances: 5 cm, 15 cm, 30 cm, and 45 cm.

Outcomes and Results

A strong correlation between the dose values and the photon counts was observed. For the large water phantom $R^2 = 0.98$ was achieved using angular filtering with the 200 − 450 keV photon energy threshold and 45 cm phantom-detector distance. Under the same collimation conditions, we obtained $R^2 = 0.8407$ for the small water phantom, $R^2 = 0.9822$ for the water-bone phantom (Fig.3), and $R^2 = 0.9797$ for the water-bone-air phantom. The use of the collimator with the same photon energy window and the phantom-detector distance gave $R^2 = 0.6804$ for the large water phantom. The collimator was not used with other phantoms due to its computational inefficiency. The code for the MATLAB system portion was verified using unit testing and visualizations. The project results indicate the method's potential to be used in clinic for dosimetric verification and treatment monitoring.

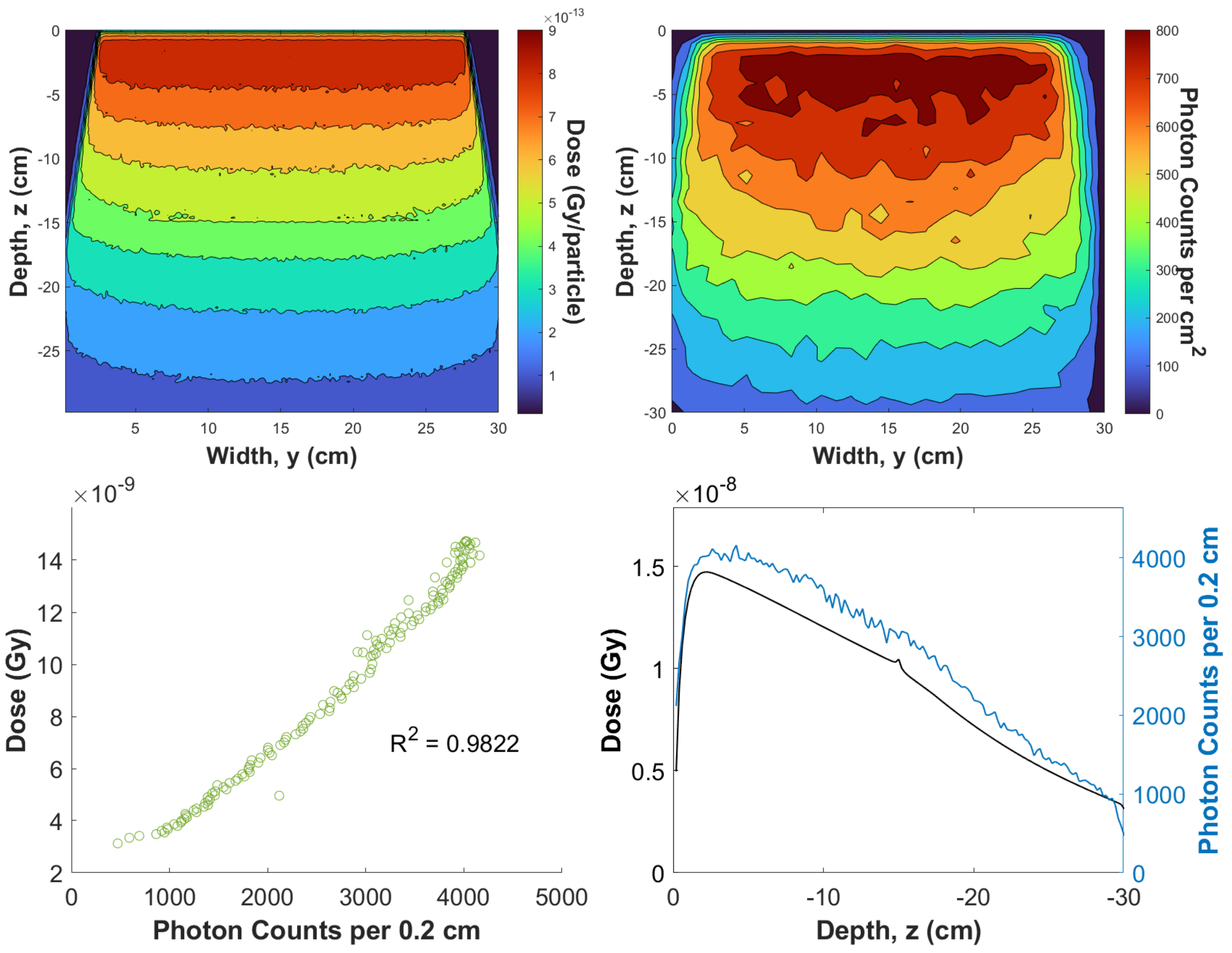

Fig. 3. Results for the water-bone phantom using angular filtering with photon energy threshold 200 − 450 keV and 45 cm phantom-detector distance

Future Work

The project will be continued by other students focusing on the characterization of the dose - photon counts relationship, the study of other photon energy thresholds and system geometry, and the comparison of the simulation results with physical measurements.

Lessons Learned

- Literature review is important
- Documentation is a key
- Teamwork is helpful when everyone contributes equally

Credits

Tatiana: 90% of class assignments & documentation, MATLAB system setup, sphere-detector photon transfer, photon collimation using angular filtering, 30% of photon collimation by the collimator, statistical analysis, studies of the water phantom size, photon energy thresholds, and the phantom-detector distances.

Samuel: 10% of class assignments & documentation, the gDPM compilation on Google Colab, collimator body, 70% of photon collimation by the collimator, definition files for the heterogeneous phantoms, size reduction of the gDPM output files, code unit-testing.

Acknowledgements

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Laboratory for Computational Sensing + Robotics

Johns Hopkins Whiting School of Engineering

Engineering Research Center for Computer Integrated Surgical Systems and Technology