Preliminary Results for VOXMAT: Phantom Model with Combination of Voxel and Mathematical Geometry

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INTRODUCTION

Recently, a computational Phantom wIth Moving Arms and Legs (PIMAL) has been developed to assess the radiation dose for realistic exposure geometries [1]. PIMAL is based on the Oak Ridge National Laboratory (ORNL) mathematical phantom and has the capability of bending arms from the shoulder and elbow; and legs from the hip and knee. Furthermore, in order to assist the user with the dose assessments and reduce the analyst's time, an accompanying graphical user interface has also been developed [1]. To our knowledge, this has been the first phantom model with freely moving abilities for dose assessments. However, this phantom model is a mathematical phantom, and the International Commission on Radiation Protection (ICRP) is moving toward voxel phantoms due to the detailed anatomical information and acceptance of these phantoms [2]. While the voxelized phantoms contain significantly more anatomical details, there is an increase in the computational burden, for both time and memory, as well as the difficulties associated with moving abilities for the limbs.

In order to address these issues, the feasibility of utilizing a combination of mathematical and voxel geometry elements to define a computational phantom representing the human anatomy is examined. In this paper, the hybrid phantom, VOXMAT, is described and the preliminary computational results are presented.

DESCRIPTION OF VOXMAT

A hybrid computational phantom, using a combination of voxelized and stylized geometry, for radiation dose assessment is under development. In this phantom, the head and torso, which contain significant anatomical details, are described using voxel geometry. The arms and legs, which contain less-detailed anatomical structures, are modeled using the mathematical equations (stylized approach). It is important to note that during the development of the hybrid phantom, VOXMAT, instead of using simple cones or cylinders for arms and legs, the equations that describe the arms and legs are revised to further resemble the shapes for arms and legs more realistically. During the construction of the arms and legs, the guidance from the CT scans was useful. Using this approach, the computational time and memory requirements are reduced while retaining the essential anatomical details for the dose estimations. Furthermore, the hybrid phantom would allow the movement of arms and legs relatively easier for radiation dose assessment for realistic postures.

The original phantom is described using 7.16 million voxels. The voxel dimensions are 2.137x2.137x8 mm. Since homogeneously distributed voxels were used to describe the whole anatomy, there was significant number of empty voxels (filled with void). Therefore, as the first step, the body was divided into three regions: the head, torso with arms, and legs. The dimensions for the surrounding box for each region were changed accordingly. For example, in the original model, the head was described using more than one million voxels and 730,998 of these were filled with void. By removing the void filled voxels surrounding the head, the number of voxels was reduced to 301,258 (~70% reduction in number of voxels). The dimensions for the box surrounding the torso and arms remained the same, since in the original model, the dimensions for the outer box were determined using these parts. However, the box surrounding the legs was resized. In the original model, more than three million voxels were used to describe the legs. Similarly, by simply removing the void filled voxels around the legs, more than one million voxels were removed from the original model. In summary, using this approach by itself, the number of voxels was reduced from 7 million to 5 million.

As the next step, the voxelized arms and legs were replaced with mathematical equations. However, during this modification, instead of using simple cones or cylinders, the arms and legs were described using combinational geometries such that they still look realistic. The shapes of the arms and legs were determined from the original fully voxel phantom. The fully voxel phantom used in this study (left) and VOXMAT, the hybrid phantom developed from this model (right), are shown in Fig. 1. As shown in the figure, using combinational geometrical models, the shape of the arms and legs are made realistic, similar to voxel phantom. The surrounding box is not shown in the figure. At the moment, the number of voxels for hybrid phantom is 3 million, which is about 60% less than the original number of voxels of 7 million.

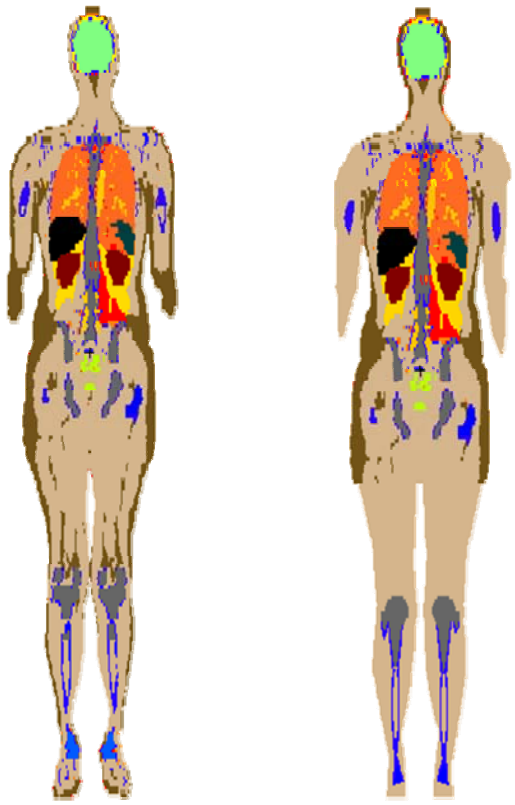

Figure 1. Fully voxelized phantom (left) and hybrid phantom VOXMAT (right). Although for VOXMAT the voxel description for arms and legs are replaced with the stylized approach, the shape is still realistic.

RESULTS AND FUTURE WORK

The organ dose computations for both phantoms, fully voxelized and hybrid phantom VOXMAT, were performed using MCNPX [3] to ensure that the modifications did not cause any statistically significant change. Computations were performed for monoenergetic neutron and photon sources for the standard ICRP source geometries: Left Lateral (LLAT), Right Lateral (RLAT), and Isotropic (ISO) geometries. For neutrons, the source energy range varied from 10^{-9} MeV to 20 MeV. For photons, the source energy range varied from 80 keV to 10 MeV. The computations were performed on a Linux cluster using 20 million particles at each energy. To reduce the statistical uncertainty at lower energies, the number of particles was increased to 100 million.

The computational results show that the organ doses from both phantoms, fully voxelized and hybrid, are in excellent agreement with each other within statistical fluctuations for both neutron and photon sources. However, the computational time and memory requirements for hybrid phantom are about 50% less than the fully voxel phantom for all these cases.

In conclusion, using the hybrid phantom approach, the number of voxels in a phantom can be reduced by a factor of two or even more, which translates into almost proportional reduction in computational time and memory requirements. Furthermore, using the stylized approach for arms and legs would allow adding the capability of moving abilities for these organs easier for realistic dose estimations for different postures.

Adding freely moving abilities for arms and legs and comparison of the results against moving abilities with fully voxel phantom is planned as future work.

REFERENCES

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