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Preliminary Study on Hybrid Computational Phantom for Radiation Dosimetry Based on Subdivision Surface

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1. Introduction

The anthropomorphic computational phantoms are classified into two groups. One group is the stylized phantoms, or MIRD phantoms, which are based on mathematical representations of the anatomical structures. The shapes and positions of the organs and tissues in these phantoms can be adjusted by changing the coefficients of the equations in use. The other group is the voxel phantoms, which are based on tomographic images of a real person such as CT, MR and serially-sectioned color slice images from a cadaver.

Obviously, the voxel phantoms represent the anatomical structures of a human body much more realistically than the stylized phantoms. A realistic representation of anatomical structure is very important for an accurate calculation of radiation dose in the human body.

Consequently, the ICRP recently has decided to use the voxel phantoms for the forthcoming update of the dose conversion coefficients [1]. However, the voxel phantoms also have some limitations: (1) The topology and dimensions of the organs and tissues in a voxel model are extremely difficult to change, and (2) The thin organs, such as oral mucosa and skin, cannot be realistically modeled unless the voxel resolution is prohibitively high.

Recently, a new approach has been implemented by several investigators [2]. The investigators converted their voxel phantoms to hybrid computational phantoms based on NURBS (Non-Uniform Rational B-Splines) surface, which is smooth and deformable. It is claimed that these new phantoms have the flexibility of the stylized phantom along with the realistic representations of the anatomical structures. The topology and dimensions of the anatomical structures can be easily changed as necessary. Thin organs can be modeled without affecting computational speed or memory requirement. The hybrid phantoms can be also used for 4-D Monte Carlo simulations.

In this preliminary study, the external shape of a voxel phantom (i.e., skin), HDRK-Man [3], was converted to a hybrid computational phantom by using the subdivision surfaces.

2. Methods and Results

2.1 Conversion of voxel model into surface model

There are three kinds of surface mostly used in 3D graphic modeling: polygon, NURBS, and subdivision surface. Fig.1 shows the feature of these surfaces.

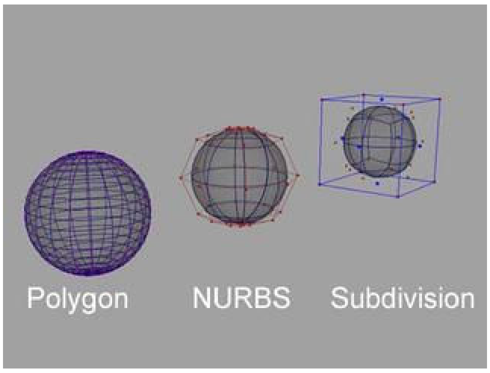

Figure 1. Polygon, NURBS, and subdivision surface

The advantages of the NURBS surface are that it is smooth and deformable. To convert the voxel model to a NURBS surface model, we can use the contours of the anatomical structures. This method, however, cannot convert complicated geometries. For example, the conversion of the external shape of the body (i.e., skin) results in a significant deformation of detailed structures including deformation of faces, fingers, toes, etc [4]. In this study, therefore, it was attempted to convert the skin of a voxel model into a subdivision surface model, instead of a NURBS surface model. The used voxel phantom is a previously developed voxel model, HDRK-Man, by using serially-sectioned color images from a cadaver of a Korean adult male.

First, the skin of HDRK-Man was converted into a polygon surface model with 3D-DOCTOR^{TM}. Many developers of the voxel phantoms have used the polygon surface model for 3-D visualization of developed phantoms. The polygon surface model is inadequate for smooth deformation.

Then, the polygon surface model was converted into a collection of NURBS surface patches, not a single NURBS surface. This had to be done to avoid the deformation of the model. It was implemented by using RAPIDFORM^{TM}, which can create a collection of NURBS patches on a polygon object automatically.

These patches must be attached together to be used for deformation. It was impossible, however, because the NURBS surfaces can be attached only if the surfaces are of identical size. Therefore, in this study, the NURBS surface patches was converted to subdivision surfaces by using MAYA 8.5. The subdivision surface is also deformable and can be attached together even if the sizes of the patches are different. The collection of the subdivision surfaces were then connected together to form a smooth subdivision surface model of the HDRK-Man skin.

2.2 Deformation of Skin

Most existing voxel phantoms are developed based on an individual in the supine posture. Sato et al. developed two voxel phantoms, JM1 and JM2, which are constructed by using CT images of the same adult male, but in the supine and upright posture, respectively [5]. In the supine posture, compared to the upright posture, the back and abdomen are flattened, and the intestines are slightly shifted towards the thoracic region so that the lungs are compressed [1]. This study adjusted only the flattened back of the HDRK-Man to a normal shape in the upright posture. This adjustment was done intuitively because there is no detailed information on the difference between the supine and upright postures. The deformation is implemented by using soft modification tool of MAYA 8.5. Figure 2 shows the HDRK-Man external surface before and after adjustment.

Figure 2. External shape of HDRK-Man before (left) and after (right) adjustment

3. Conclusion

This study converted the external shape of a voxel model, HDRK-Man, to a subdivision surface model, which was then adjusted for the upright posture. This study mainly shows that it is possible to develop a very high quality hybrid computational phantom by using a collection of subdivision surfaces. Our next step is to convert this subdivision surface model back to the voxel model for Monte Carlo dose calculations. The technique presented in this paper will be used to adjust the topology and dimensions of the organs and tissues in HDRK-Man and to develop various deformed models of Korean voxel models in the future.

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