DEVELOPMENT OF SMART VOXEL MODELS OF WHOLE HUMAN-BODIES FOR NUMERICAL DOSIMETRY

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Abstract: Few voxel models of whole human-bodies are available for numerical dosimetry with realistic modeling. We have therefore developed several smart voxel human models and a 3-D voxel visualization system. At first, in this paper, whole human-body voxel models of Japanese average adult male and females are introduced. Then, applications of the several smart functions, i.e., variable voxel-size, variable figure, and variable posture, are described. Finally, the 3-D voxel visualization system for multipurpose pre/post processes of numerical simulation is demonstrated. These new voxel models enable more realistic numerical simulations.

Keywords: Voxel model, numerical simulation, 3-D visualization, CAD, FDTD, and SAR

1 Introduction

With the rapid rise in computer performance, numerical simulation has become indispensable for radiofrequency dosimetry. Voxel human models have therefore become one of the most important infrastructures for numerical dosimetry. Recent advanced medical diagnostic technology, especially magnetic resonance imaging (MRI), allows us to develop very realistic voxel human models although time-consuming manual processes done by medical staff are still required to identify the tissue types of the numerous voxels in the models, and to correct and supervise this identification.

The needs for voxel human models will continue to increase as various wearable/mobile wireless communication terminals are developed. Currently available voxel human models, however, have some limitations with regard to modeling realistic situations when such devices are used.

We are therefore developing smart voxel human models which will allow realistic modeling and improve the accuracy of the numerical dosimetry. We are also developing a 3-D voxel visualization tool as a multipurpose pre/post processor for numerical simulation using voxel models. This paper summarized our research in these areas.

2 Whole Human-Body Models

Many voxel models of human heads have been developed and used for numerical dosimetry regarding cellular phones [1, 2]. Only a few voxel models of whole human-bodies have been developed, though, and most of those developed are based on a European/American adult male [3–6].

Some of us have participated in a project to develop voxel models of whole human-bodies based on Japanese average adult male and female volunteers [7, 8]. These models consist of 2-mm cubical voxels, each of which is identified with over 50 types of tissues and organs. 3-D views of these models are shown in Fig. 1. Our models are compared with other whole-body models in Table 1. The height and weight of the Japanese models are significantly different from those of the other models, which suggests that the European/American human models are not always appropriate representation of Japanese (Asian) people.
Table 1: Comparison with other whole-body models.

<table>
<thead>
<tr>
<th></th>
<th>Original Data</th>
<th>Sex</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>Number of Tissues</th>
<th>Voxel Size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ours [7, 8]</td>
<td>MRI</td>
<td>Male</td>
<td>173.2</td>
<td>65</td>
<td>51</td>
<td>$2 \times 2 \times 2$</td>
</tr>
<tr>
<td>Ours [7, 8]</td>
<td>MRI</td>
<td>Female</td>
<td>160.8</td>
<td>53</td>
<td>51</td>
<td>$2 \times 2 \times 2$</td>
</tr>
<tr>
<td>Norman [3]</td>
<td>MRI</td>
<td>Male</td>
<td>176.0</td>
<td>73</td>
<td>37</td>
<td>$2.077 \times 2.077 \times 2.021$</td>
</tr>
<tr>
<td>Gandhi [4]</td>
<td>MRI</td>
<td>Male</td>
<td>176.4</td>
<td>71</td>
<td>29</td>
<td>$1.974 \times 1.974 \times 3$</td>
</tr>
<tr>
<td>Dawson [5]</td>
<td>MRI &amp; VHP†</td>
<td>Male</td>
<td>177.0</td>
<td>76</td>
<td>34</td>
<td>$3.6 \times 3.6 \times 3.6$</td>
</tr>
<tr>
<td>Brooks [6]</td>
<td>VHP†</td>
<td>Male</td>
<td>187.1</td>
<td>105</td>
<td>43</td>
<td>$1 \times 1 \times 1$</td>
</tr>
</tbody>
</table>


Figure 2: Example of variable voxel-dimension models.

3 Smart Voxel Models

3.1 Variable voxel-dimension models

The spatial resolution of the Japanese whole-body models is 2 mm. These models can not be used for finite-difference time-domain (FDTD) calculations at frequencies higher than about 3 GHz because the dimension of the voxels in the human models must be sufficiently smaller than the internal wavelength in the human model.

A simple solution is to halve the voxel size, which can double the applicable frequency. If the shape of the curvature boundaries remains a rough staircase modeled with the original or coarse voxels, however, errors due to such coarse modeling could become significant at higher frequencies. This is why we have developed new models with variable voxel dimensions [9].

The basic function of the new models is a smoothing algorithm which improves the rough outline of the internal tissues and organs as well as the boundary between skin and air when the spatial resolution of the voxel models is made more fine.

An example of this function is shown in Fig. 2. The smoothness of the outer and internal boundaries is clearly improved in the 1-mm resolution model.

3.2 Variable age (figure) models

Numerical dosimetry for children is a particularly important issue. The development of voxel models of children is difficult, though, because ethical considerations limit the collection of anatomical data from children with medical diagnostic equipment. We have therefore tried to transform the original adult models to child models [10].

The original models were inhomogeneously rescaled because the human figure is significantly different for children and for adults. An example of the application of this rescaling algorithm is shown in Fig. 3.

In applying this rescaling algorithm, ratios of anthropometric dimensions between the original model and the transformed one are required. Because there is little relevant statistical data available from children, especially younger than seven year old, we performed anthropometric measurement of fifteen children.

The dimension of each part of the body was measured by staff experts at the Research Institute of Human Engineering for Quality Life (HQL). 66 anthropometric dimensions were obtained during a two-hours session for each child. From the data obtained from the fifteen children, we determined the average anthropometric dimensions of three, five, and seven year old children. 3-D views of the average shape of a three year old child are shown in Fig. 4.
3.3 Variable posture models

Because most whole-body voxel models are based on MRI data, their postures are always as if the subject was standing. This can limit the simulation of realistic situations, such as when the subject is sitting and using a laptop PC with a wireless LAN connection on their knees [11]. Power absorption under the whole-body resonant conditions is also strongly dependent on the posture of the human body [12].

We have therefore developed human-body models for any posture based on a CAD software product. This software includes a statistical dataset of anthropomorphic dimensions and can change the posture of various human bodies as shown in Fig. 5.

After the posture of the human bodies is modified, a newly developed software module outputs the voxel data with any voxel resolution as shown in Fig. 6.

The models described so far in this section are homogeneous because only the outline of the human bodies can be obtained with the CAD software. This is a significant shortcoming because an internal inhomogeneous structure can affect electromagnetic power absorption in the human body.

We have therefore been developing new software to apply to inhomogeneous voxel models. Preliminary results are shown in Fig. 7. As can be seen, our newly developed interpolation algorithm can connect the separated parts around a bent elbow of an inhomogeneous model.

4 3-D Visualization

In numerical simulations with voxel human models, 3-D visualization is also important because it enables accurate positioning between human bodies and electromagnetic sources such as cellular phones as well as detailed and general investigation of calculated results. Few 3-D visualization tools for voxel models, except those included in professional FDTD simulators, are available. We have therefore developed multipurpose 3-D visualization tools for voxel human models which can be used for FDTD solvers as well as other simulations using voxel models (e.g., impedance methods for extremely low frequency regions and thermodynamics simulation based on finite-difference formulations).

Although an iso-surface view can be quickly dis-
played, this view is not accurate enough to check the location and shape of voxel models, as shown in the left picture of Fig. 8. Voxel visualization, on the other hand, allows accurate verification, as shown in the center picture of Fig. 8. Also, as shown in the right picture of Fig. 8, the calculated SAR distribution can be realistically visualized.

5 Summary

We have developed several variable voxel-dimension models based on a new smoothing algorithm developed newly. This function enables FDTD simulations at over 3 GHz with sub-milimeter voxel models.

We have also developed variable age (figure) models based on an inhomogeneous scaling algorithm. This function can be used for detailed dosimetry of human bodies with various figures; children, pregnant women, and so on. To develop the voxel models of children, we have obtained a statistical dataset of the anthropomorphic dimensions of children.

Furthermore, we have developed variable posture models based on CAD software and a new interpolation algorithm. These models allow more realistic numerical dosimetry, as reported in [13] where the induced current in the human body who cooks with induction heater (IH) equipment was calculated with the variable posture model.

To utilize these voxel models, we have developed a 3-D voxel visualization system. The 3-D voxel visualization allows us to accurately check the geometry of voxel models and investigate results from numerical solvers.

In our future work, we will continue to improve these models. We are also developing a large-scale visualization system because the memory capacity required by the whole-body voxel models sometimes exceeds the capabilities of a 32-bit computer.

Through these studies, the reliance of numerical dosimetry can be improved and a safer, more appropriate radiofrequency environment realized.

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References


