DEVELOPMENT OF BIOLOGICAL VOXEL-BASED COMPUTATIONAL MODELS FROM DICOM FILES FOR 3-D ELECTROMAGNETIC SIMULATIONS

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ABSTRACT

Biological voxel-based computational models are constructed to be used in dosimetry calculations. These models are employed in dosimetry calculations to probe the effects of electromagnetic interaction between electronic equipments and biological structures. In this study, the construction way of the biological voxel-based numerical models have been described. DICOM format, which is a medical image file format, has been also clarified. We have developed a medical program called DFP (Dicom File Processing) in order to process DICOM files. And also we developed a voxel-based computational adult human head containing grey matter, white matter, skin, internal air of head and external air from MRI images in DICOM files in order to describe elaborately how can be biological voxel-based computational models developed.

I. INTRODUCTION

Electromagnetic simulations in the computer environment are very important on behalf of investigating the effects of electromagnetic fields without other undesired field contributions. These effects are important but it is not the scope of this paper. Biological voxel-based computational models provide facility to be able to estimate the amount of RF energy so-called specific absorption rate (SAR) deposited in the tissue by electromagnetic simulations. Calculations for electromagnetic interaction between electronic equipments and biological structures such as compliance testings in the computer environment are done with biological voxel-based computational models for accuracy of calculations. Numerical voxel-based computational models of biological structures are used in various areas such as radiotherapy, nuclear medicine and to investigate the effects of electromagnetic fields. Tomographic medical imaging techniques have allowed the construction of digital three-dimensional computational models based on the actual anatomy of individual humans. These are called voxel models, tomographic models, phantoms or tomographic voxel models interchangeably. Their benefits lie in their faithful representation of human anatomy [1]. The first computational models were the mathematical models of adults and children from the Oak Ridge National Laboratory [2, 3, 4, 5]. Since the internal organs of these models were represented by equations for planes, spheres, cones, ellipsoids, elliptical cylinders, cylinders, these models were mathematical. However organs of these models do not conform to the shape of real organs.

Increasing use of medical imaging types, particularly computed tomography (CT) and magnetic resonance imaging (MRI) have provided high resolution cross-sectional digital images of internal anatomy [1]. The construction of biological voxel-based models is rapidly increasing to be able to do calculations with more realistic biological voxel-based computational models to decrease the inconsistencies associated with calculations.

In this paper we have demystified how can be biological voxel-based computational models constructed from medical images in DICOM files for three-dimensional electromagnetic simulations. We have constructed voxel-based computational adult female human head model containing gray matter, white matter, skin, internal air, external air to describe elaborately the construction way. And we have developed a medical program called DFP (Dicom File Processing) program that provides easy access to medical images, modality, metadata, patient information within DICOM files.

II. DICOM FILE FORMAT

The DICOM (Digital Imaging and Communication in Medicine) format describes how to compose messages to send between imaging modalities (*e.g.*, Computed Tomography (CT), Magnetic Resonance (MR) and ultrasound devices). These messages can also be written to files for offline. DICOM-formatted messages combine images and metadata to create a rich description of a medical imaging procedure. DICOM format makes it easy to acquire and put medical images into a file. DICOM format is used for exchanging image and metadata by the users of bioimaging techniques. It is becoming more prevalent in the medical field [6]. Besides the DICOM file format, there are plenty of digital image file format that are used by radiologist such as Joint Photographic Experts Group (JPEG) [7], Tagged Image File Format (TIFF) [8], Portable Network Graphics format (PNG) [9], Graphic Interchange Format (GIF) [10], Joint Photographic Experts Group 2000 format (JPEG 2000) [7]. Simple MRI image and header within the DICOM file is shown in Figure 1.

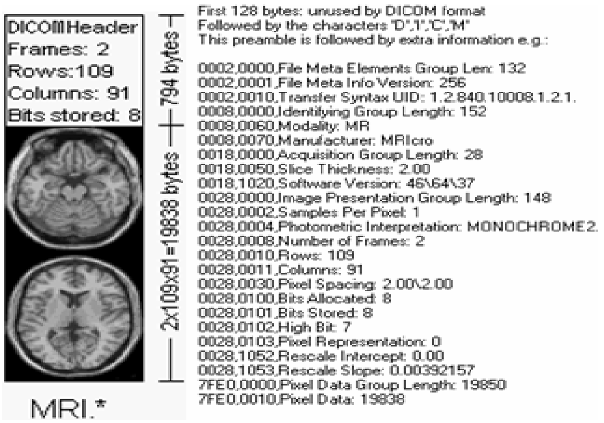

Figure 1. MRI image and header within the DICOM file

III. MATERIAL AND METHODS

There are plenty of file formats in the medical field but we used DICOM files due to the required informations in the header for the construction of voxel-model. The construction way of the tomographic voxel-based computational models is starting by stacking up the medical images within the DICOM files without modification the orders of the DICOM files. As it can be seen in Figure 2. The developed medical program in our laboratory, called DFP, can stack up DICOM files and gives us as an one DICOM file.

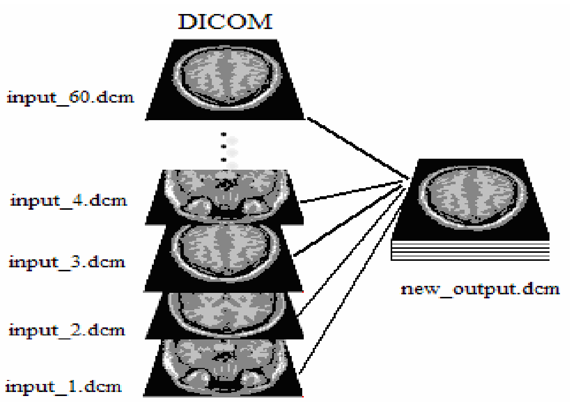

Figure 2. Stack up of the medical images within the DICOM files without modification the orders of DICOM files

Cross-sectional images or slices known as a volumetric dataset are used to add depth to an image. This process I called voxelization. These cross-sectional images or slices are made up of pixels. The space between any two pixels in one slice and the distance any two slices are referred to as interpixel distance and interslice distance respectively wich represent a real-world distance and depth individually. The dataset is processed when cross-sectional images are stacked in computer memory based on interpixel and interslice distances to accurately reflect the real-world sampled volume. Then, additional slices are created and inserted between the dataset's actual slices so that the entire volume is represented as one solid block of data [11].

DESCRIBING THE HEADER ATTRIBUTES

Useful informations can be learned from header within the DICOM files. The header within the one of the DICOM file, which we selected, can be seen in Figure 3.

```
0008,0060,Modality=MR
0018,0020,Scanning Sequence=GR
0018,0021,Sequence Variant=SP
0018,0022,Scan Options=SP\PFF
0018,0023,MR Acquisition Type=3D
0018,0024,Sequence Name=3dgrass
0018,0050,Slice Thickness=3
0018,0080,Repetition Time [TR, ms]=35
0018,0081,Echo Time [TE, ms]=5
0018,0084,Imaging Frequency=63.8614
0018,0087,Magnetic Field Strength=1.5
0018,0088,Spacing Between Slices=0
0028,0004,Photometric Interpretation=MONOCHROME2
0028,0010,Rows=256
0028,0011,Columns=256
0028,0030,Pixel Spacing=0.859375 0.859375
0028,0100,Bits Allocated=16
0028,0101,Bits Stored=16
0028,0102,High Bit=15
0028,0103,Pixel Representation=1
0028,0106,Smallest Image Pixel Value=0
0028,0107,Largest Image Pixel Value=80
7FE0,0010,Pixel Data=131072
```

Figure 3. The header within the one of the DICOM file

As it is shown in Figure 3, important informations to construct voxel-based computational models can be seen elaborately. (0080,0060) values represent DICOM tag of modality attribute and MR label represents the attribute description, here it represents MRI, in Figure 3.

Image Pixel Data is stored within the Value of the Pixel Data Element (7FE0,0010). The order in which Pixel Data (7FE0,0010) for an image plane is encoded is from left to right and top to bottom, a row at a time in Figure 4. Figure 5 illustrates the use of the data elements for Bits Allocated (0028,0100), Bits Stored (0028,0101) and High Bit (0028,0102) in the encoding of pixel for header file in Figure 3. Sample pixel cells are seen before being encoded in byte streams in Figure 5. A pixel cell is the container for a pixel sample value and optionally additional bits. A pixel cell exists for every individual pixel sample value in the Pixel Data. The size of the pixel cells is specified by Bits Allocated (0028,0100) and is greater than or equal to the Bits Stored (0028,0101). The placement of the pixel sample values within the pixel cells is specified by High Bit (0028,0102) [12].

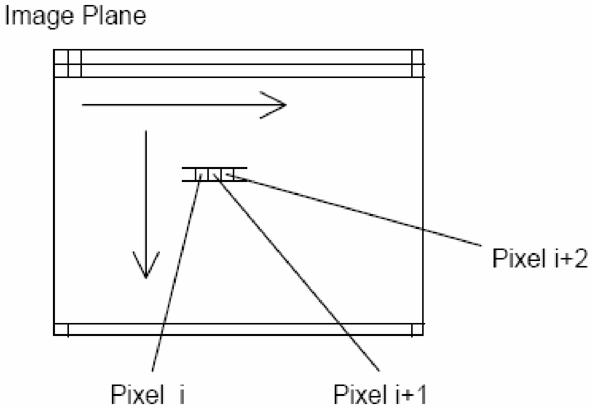

Figure 4. An Image Pixel Plane

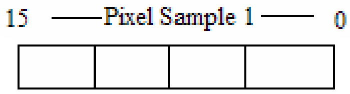

Figure 5. Example of Pixel Data Cell

As it can be seen from the header in Figure 3, Photometric Interpretation attribute is MONOCHROME2. MONOCHROME2 is representing a grey (black to white) intensity scale of colour mapping. Slice Thickness, Spacing Between Slices, Rows, Columns, Pixel Spacing, Smallest Image Pixel Value, Largest Image Pixel Value attributes are the key parameters to able to construct voxel-based computational models.

Pixel Spacing attribute values represent pixel size width and pixel size height respectively. Rows and Columns attribute values represent height in pixels and width in pixels respectively. The Field Of View (FOV) of our data or the distance across our image, is the product of the pixel size and the width in pixels values of the image. A voxel is a three-dimensional pixel. The size of a voxel is the product of the pixel size width, the pixel size height and Slice Thickness plus Spacing Between Slices. The volume of a slice is the product of the voxel size, width in pixels and height in pixels. The total volume of this dataset is the product of the volume of a slice and the total number of slices. DFP program can give us these values easily as an excel file.

RAW MRI IMAGES WITHIN THE DICOM FILES

The montage of the MRI images within the DICOM files can be seen in Figure 6. These DICOM files were taken from internet [13]. The raw 60 MRI images in DICOM files were contiguous slices from volunteer. The volunteer was a 27-year-old female. The examination was performed with a MRI machine (GE Signa 1.5 Tesla MRI System) by selecting 3D Spoiled Gradient Recalled (3D SPGR) image technique. These informations can be learnt from headers within the DICOM files. These acquisitions are generally faster than spin echo sequences and show better gray to white ratios in the brain. The number of slices was 60 and each slice consisted of a matrix of 256x256 pixels with grey values ranging from 0 to 332. The data was stored as a 256x256x60 two-byte array. Pixel size width of our data is 0,859375 mm, pixel size height is 0,859375 mm, slice thickness is 3mm, spacing between slices is 0 mm, width in pixels is 256, height in pixels is 256. In this case, the voxel size is 2,215576 mm^3, slice volume is 145200 mm^3, total volume of dataset is 8712000 mm^3, FOV is 220 mm, the spatial resolution is 0,85x0,85x3 mm^3.

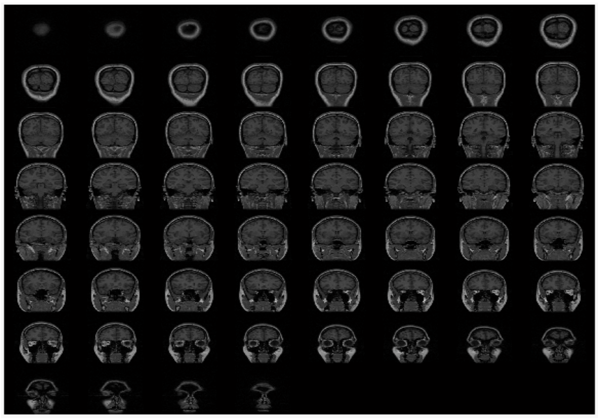

Figure 6. Montage of employed MRI images within the DICOM files

SEGMENTATION TOOL USED

We used DFP (Dicom File Processing) program to able to read, view, write new DICOM files, extract voxel informations within the DICOM files for giving as an excel file, select ROIs, threshold images.

The morphological operations such as object erosion, dilation and blob analysis on binary images used during the segmentation process. Futrhermore, the binary operator "and" was used.

TISSUE IDENTIFICATION

The pixels belonging to a tissue are assigned a tissue identification number that replaces their original grey scale value. We assigned to each tissue different red-green-blue (RGB) code. With this way all the pixels that belong to a tissue can be identified and distinguished from pixels belonging to other tissues.

SEPARATING HEADER AND IMAGE WITHIN THE DICOM FILES

After we have digitized MRI images, we stacked up them like in Figure 2 and stored them as a 15360x256 data matrix. We used DFP program to separate header and image within the DICOM files. The reason for separating is to obtain only images. After separation, we obtained only MRI images as a .tiff file format losslessly. This means that we have converted .dcm files to .tiff file format without header informations.

THE CONSTRUCTION OF VOXEL-BASED MODEL

We used CST Microwave Studio in order to construct voxel-based model [14]. We created .vox and .txt file in ASCII editor. The .vox file contains the information needed to build the three-dimensional voxel-based model. The .txt file contains the electrical and magnetic properties of the tissues that were segmented. In Table 1, we gave an example .txt file that contains electrical and magnetic properties of tissues at 1800 MHz. These properties can be changed according to the simulation frequency. Tissue dielectric properties have obtained from internet [15]. Finally we have had three type of files named .vox, .txt and .tiff. The .tiff file contains the dimensional information of the head in binary format. CST Microwave Studio can use all these files to construct voxel model.

Table 1 . Tissue properties at 1800 MHz

Tissues	ID	ε_r	σ [s/m]	ρ [kg/m^3]	R	G	B
Air (external)	0	1.0	0.0	1.30	0	0	0
Air (internal)	1	1.0	0.0	1.30	255	255	128
Skin	3	38.87	1.1847	1125.0	245	150	160
Gray Matter	4	50.07	1.3911	1038.00	185	0	255
White Matter	5	37.01	0.9149	1038.00	182	255	0

IV. RESULTS AND DISCUSSION

We can see the constructed voxel-based computational adult female human head model containing gray matter, white matter, skin, internal air, external air in Figure 7. The nose region of the head doesn't seem due to the one cross sectional acquisition of nose MRI image instead of more than one cross sectional. The calculation of the microscopic quantities with computational models is not possible due to the insufficient resolutions. However, it is possible to combine the results of macroscopic modelling with electrical models of cell membrane to calculate cellular fields and potentials. In this research, we demystified a way of developing biological voxel-based computational models from medical imaging modality (MRI) in DICOM files. Further analysis and studies should be done for more tissue segmentation and more realistic models. Because tissue segmenting is a very time-consuming and laborious process.

V. CONCLUSION

In bioelectromagnetics it is important to have numerical models of the biological structures in order to carry out simulations of the electromagnetic interaction between biological structures and electronic equipments. Construction of biological voxel-based computational models from medical images within the DICOM files is possible with current technology and the more realistic voxel-based computational models can be obtained by increasing the resolution of the medical images within the DICOM files.

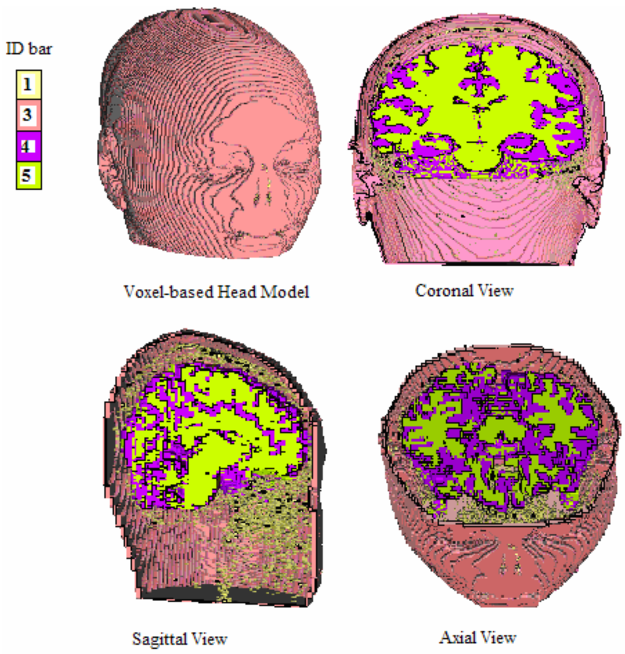

Figure 7. Voxel-based adult female human head model, Coronal view, Sagittal view, Axial view, ID bar

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