Computations of SAR Distributions for two anatomically-based models of the human head using CAD files of commercial telephones and the Parallelized FDTD code

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Abstract

The Finite Difference Time Domain (FDTD) method is well suited for the computation of bio-electromagnetic effects and has become the method of choice for most researchers in this area. There does however remain some limitations on its use. Firstly the FDTD method requires large amounts of memory and computational power. The size of the model is dependent upon both the physical size of the model and its resolution. Higher frequencies of operation require higher resolutions. This can place the solution of some problems outside the capabilities of the technique. Secondly the representation of the problem (i.e. the head and the telephone) can cause some difficulties. Often the telephone has to be represented by a series of boxes which approximate the shape of the actual device. The paper addresses these two problems. The problem size is accommodated by the use of a parallelized version of the FDTD method, which is run on large parallel processing machines such as the IBM SP-2. Additionally a method of inputting data from the Computer Aided Design (CAD) files of the telephone has been developed. These two techniques are used in combination with two head models which have been developed from MRI images of two human subjects. The usefulness of the techniques developed and comparisons of the specific absorption rates (SARs) in the two models is discussed.

Parallel Processing

One method which can be used to increase the capability of an existing numerical technique is to adapt the algorithm to run on a parallel processing platform. These platforms consist of a number of processing elements. Although many types of parallel processing platforms exist, it is the coarse grain distributed memory platform which is of relevance to this work. In this type of system each of the processing units consists of a power processor (CPU and FPU), and an amount of locally addressable memory. The power of each unit is therefore of the same order as an individual UNIX workstation, and in fact the technology is essentially the same. With this type of approach each of the units forms part of a larger system, the units being able to communicate data between themselves via a high speed communications network. In order to take advantage of such a system it is first necessary to subdivide or partition the computation in the original algorithm so that it can be computed on a number of processors. Obviously for most algorithms communication will be required between individual processors. As this communication introduces a time overhead into the numerical evaluation it is necessary to maximize the ratio of computation to communication. A popular metric for expressing this ratio is the speedup S of the resulting parallel algorithm. This is expressed in equation 1.

$$S = \frac{T_n \times n}{T_1} \qquad (1)$$

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where T_n is the execution time on n processors.

A parallel FDTD algorithm

The FDTD algorithm is well suited to solution on distributed memory parallel processing systems as the field components on one cell of the geometry can be evaluated from fields on the adjacent cells (i.e. there is only a local data requirement). As a result the three dimensional problem space can be cut into smaller volumes, with solution on each of these volumes being possible in isolation if information from the relevant edges of surrounding volumes can be made available. As the computational load of each processor is based upon the volume of the problem it has been assigned and the communication upon the surface of this volume, providing the problem is of sufficient size an efficient algorithm results.

For the FDTD method to be of practical use in the simulation of bio-electromagnetic problems various features have been added. Retarded time boundary conditions have been used to terminate the FDTD problem space. Routines have also been added to compute the power radiated from the FDTD grid, the power absorbed and SAR induced in the dielectric models. The retarded time boundary conditions[1] and the radiated power computation have been parallelized within the main parallel FDTD code. However the computation of other required quantities (i.e. absorbed power and SAR) have been incorporated in a post processing tool. As the problem size is increased the amount of output from the code is also greatly increased. As each processor only computes the fields in a section of the problem space, the most rational method of outputting data is to allow each processor to write a file containing the relevant field values from that section of the problem. As both the absorbed field and SAR calculation can be performed on a cell by cell basis the post processing tool can read the files produced by each processor and compute these values. The post processing tool can also be used to produce sections/volumes of the processed results for visualization.

CAD input of the mobile telephone

One of the major problems with the evaluation of the absorbed radiation from the various devices in the human body has been the description of the device itself. Whilst accurate models of the human head and body have been developed by segmenting MRI images the telephone handset has been described by a rectangular box. In most circumstances the telephone description can be adjusted until its near field radiation pattern agrees with the measured data. However this can be a time consuming process and can diminish confidence in these numerical modeling techniques. To overcome this limitation a method has been developed to convert the files from CAD packages employed in design of the telephone into a form which can be used with the FDTD algorithm. Figure 1 shows the model of the telephone and figure 2 the FDTD problem space containing the telephone in a realistic position next to a human head.

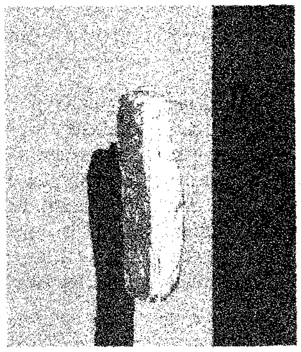

Figure 1 : The telephone as imported from the CAD file (resolution : 1.974x1.974x3.0mm).

Figure 2 : The telephone next to the head model.

Comparison of two head models

Two head models have been used in this work. The first is classified in a resolution of 1.974mm in the x and y dimensions and 3.0mm in the z dimension and the second to a cell size of 0.9375mm in all three dimensions. The purpose of using two models at different resolutions is two fold. Firstly a comparison can be made to determine how the SAR distribution is different between subject and secondly to determine the validity of the lower resolution model at higher frequencies (some digital mobile telephone systems now operate at 1900MHz). The model sizes and the FDTD problem space size (the size of the model including the telephone) are shown in table 1.

Table 1 : Sizes and solution times of the two models.

	Model 1 1.974×1.974×3.0mm	Model 2 0.9375mm
Model Size (voxels)	103×114×85	226×260×282
FDTD Size to include source (FDTD cells).	153×154×130	280×295×304
Memory Requirement	110.2 MBytes	670.2 MBytes
Solution Time single workstation	60 minutes	36 hours (estimated)
Solution Time on 8 node SP2	9 minutes	4.9 hours

A simulation using the lower resolution model can easily be accommodated on a single powerful workstation. However the higher resolution model requires significantly more resources. Eight processors of an IBM SP-2 machine were used for this simulation. The required solution times are also shown in table 1.

The two head models were used to find the maximum peak and averaged SAR (over 1g of tissue) in the head as a result of radiation from a mobile telephone operating at 1900MHz.

It has been argued that the resolution of 1.974 x 1.974 x 3.0 mm head model may not be sufficiently high enough for simulations at 1900MHz. In order to demonstrate the validity of this model a comparison has been made between the two models and these are given in table 2.

Table 2 : The SAR values for the two head models.

Model	Peak SAR	Averaged SAR
1.974x1.974x3.0mm	5.79W/kg	1.63 W/kg
0.9375mm	10.97W/kg	1.68 W/kg

Figure 3 is a graph showing the speedup of the parallel FDTD code used in the simulation of the 1.974 x 1.974 x 3.0 mm head model with a mobile telephone.

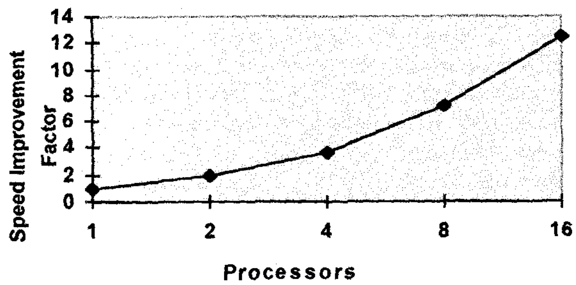

Figure 3 : Speedup of the parallel FDTD code.

Conclusions

This paper has demonstrated that using a parallel processing computer, two advantages result. Firstly a greatly reduced solution time is achieved for smaller problems, and secondly larger problems, which are beyond the capability of a single workstation are solvable. Also the mobile telephone can be represented with much greater precision by using the information contained in the CAD files used to design the device. The amount of effort required to achieve an accurate model of the telephone is also greatly reduced. Another advantage of using CAD file input is that once the technique is perfected the need to compare the near field radiation with measured data should be removed. Finally the comparison of the averaged SAR values from the two models indicates that the lower resolution model is sufficient to carry out simulations at 1900MHz.

References

[1] S.Berntsen, and S.N.Hornsleth, "Retarded Time Absorbing Boundary Conditions", *IEEE Transactions on Antennas and Propagation*, Vol. 42, pp. 1059-1064, 1994.