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Combination of DG-FDTD with a Substitution Model for Calculating Local Dosimetry in a Variable and Highly Multiscale Problem

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Abstract—This paper proposes a method to estimate human exposure to electromagnetic field radiation in a variable and highly multiscale problem. The electromagnetic field is estimated using a combination of two methods: a rigorous time domain and multiscale method, the DG-FDTD (Dual Grid Finite Difference Time Domain) and a substitution model based on the superposition principle and the use of transfer functions. The association of these methods is applied to simulate a scenario involving an antenna placed on a vehicle and a human body model located around it. The purpose is to assess the electromagnetic fields in the left eye of the human body model. It is shown that this combination permits to analyse many different positions in a fast and accurate way.

Index Terms—EM analysis, multiscale, numerical dosimetry.

I. INTRODUCTION

Numerical dosimetry is an essential approach for the assessment of human exposure to electromagnetic radiation. In order to be more realistic to the actual exposure conditions, it is necessary to consider different environments involving large structures. In this context, it is common to treat very small elements compared to the overall size of the scenario. Then, we clearly face a contrast of scale which poses difficulties for electromagnetic simulations. In addition to these multiscale aspects, dosimetry problems have naturally a variable feature as the position of the person or its orientation. This variability is a challenge for numerical dosimetry which must be able to assess the exposure for a variety of configurations of the problem.

To solve the multiscale problem, the choice of the DG-FDTD [1], [2] turns out to be judicious. Indeed, this method has shown that it can effectively treat a highly multiscale dosimetry problem [3]. Although this method is fast, this approach is not suitable to solve the second issue because the multiplication of simulations leads to prohibitive computation time.

To handle the problem of variability, several solutions have been proposed. Most of them are based on the construction of an alternative model for rapidly assessing exposure. Many of these models are based on statistical approaches such as neural networks [4] or stochastic collocation [5]. However, the construction or implementation of these tools requires a large number of costly IT resources including electromagnetic

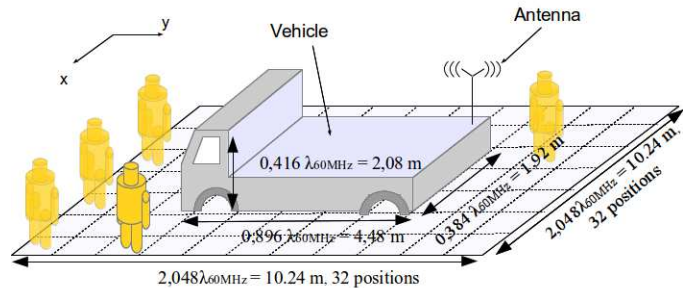


Fig. 1. Selected scenario

simulations, computer memory or datas.

In this paper, we propose a fast substitution model whose construction requires few electromagnetic simulations. It is composed of transfer functions and operates using the superposition theorem. In addition, we combine the DG-FDTD with this model to treat effectively multiscale scenarios with variable parameters. Firstly, the selected scenario is described. Then, The classic DG-FDTD approach is detailed. The next part presents the substitution model and its association with the DG-FDTD method. An application is performed for one position. To finish, the electromagnetic fields are assessed for several positions of the human body model using the classic DG-FDTD method and the combination of the methods.

II. PRESENTATION OF THE SELECTED SCENARIO

The purpose of this study is to calculate the electromagnetic fields in an eye of a whole human body located near an antenna onboard a vehicle (figure [?]).

The calculation of the fields must be carried out for different positions of the person around the vehicle. The vehicle and the person are located in the near field of an antenna. The eye is very small compared to the rest of the environment. Thus, we face a multiscale problem. The studied frequency point of study is at 60 MHz. With this scenario, 888 positions are considered.

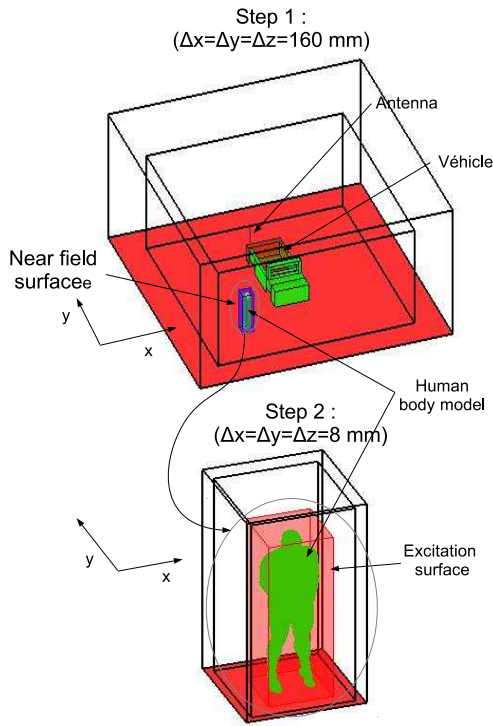


Fig. 2. Application for one position

III. PRINCIPLE OF THE DG-FDTD METHOD AND APPLICATION FOR ONE POSITION

A. Principle of the DG-FDTD method

The principle of the DG-FDTD method is to decompose a FDTD calculation in several steps performed sequentially [2], [3]. Each step involves a FDTD volume with its own resolution. The transfer of electromagnetic datas is realised through a sampling surface and an injection one.

B. Application for one position

The description of the simulation is presented in figure 2 and the parameters are given in table I. "Electromagnetic zoom" tool proposed by the DG-FDTD is used on the study.

The first step consists of a simulation with a large mesh and describing the whole problem. In fact, The mesh is chosen in a suitable way in order to describe all the elements of the scenario: the vehicle, the transmitter and the human body model. A near field surface is inserted around the person. The field collected in the first step is used in the second step to excite the volume describing more finely the human body model. This last step permits to compute in a more precise way the fields in the left eye.

The computation times associated with each step are reported in Table II. It is clear that step 2 is the most consuming in time and numerical resources. With the purpose of processing a new position of the person around the vehicle using DG-FDTD method, it is necessary to restart the two

TABLE I
SIMULATION PARAMETERS OF DG-FDTD METHOD

	First step	Second step
Time Step	292.5 ps	14, 626 ps
Spatial resolution ($dx \times dy \times dz$)	(160 × 160 × 160) mm	(8 × 8 × 8)mm
Observation time	300 ns	300 ns

TABLE II
RESULTS OF DG-FDTD SIMULATIONS

	Computing time
First step	0.56 min
Second step	356.48 min

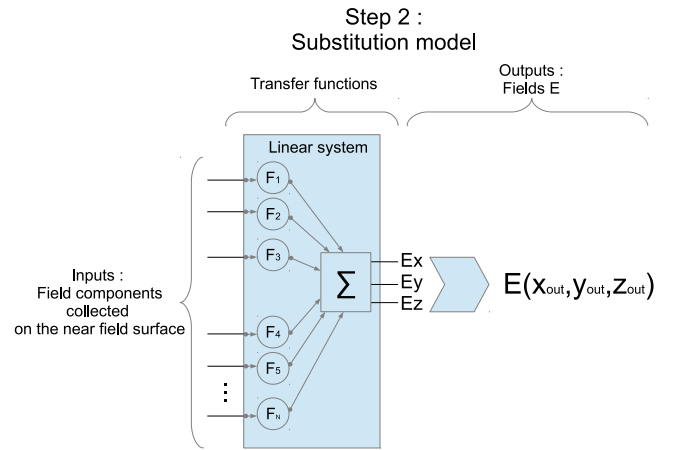


Fig. 3. Architecture of the substitution model

steps. However, in assuming only a change of person position, the FDTD volume of the first step changes but the second one remains the same. Only excitation fields differ. Based on this property, we propose to replace the second step with a substitution model which quickly calculates the field at an internal point of the body (the left eye in this case) from the excitation field collected in step 1.

IV. SUBSTITUTION MODEL

A. Principle

The substitution model intends to rigorously replace the second steps of the DG-FDTD calculation presented in the previous section. The input data of this model are the N field components on the near field surface collected in step 1. The output data are the three components of the field at the center of the human body eye model (step 2).

In the frequency domain and using the superposition principle, the last step of the DG-FDTD can be replaced by a linear system compound of N inputs and three outputs. Indeed, the superposition principle permits to compute the output field through the sum of contributions of input field components (figure 3 and figure 4).

To determine the N transfer functions effectively without performing N electromagnetic simulations, the reciprocity

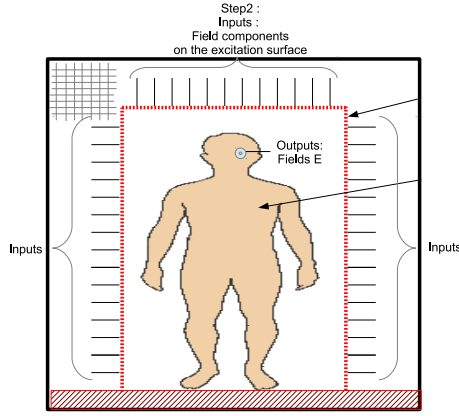


Fig. 4. Sketch of the substitution model

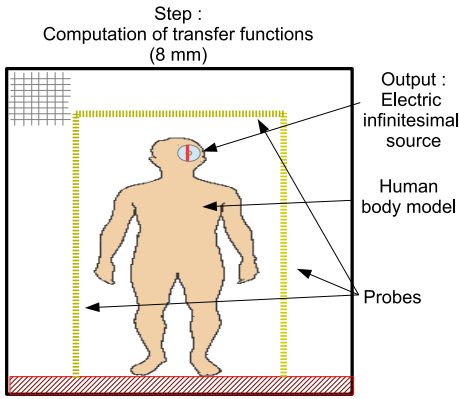


Fig. 5. FDTD simulation for the computation of the transfer functions

principle is used. By defining a reciprocal problem in which sources are placed at the three outputs, it is possible to calculate all transfer functions only with three electromagnetic simulations (figure 5). It should be noted that the approach could be generalized to more outputs (several field points, for example).

The three electromagnetic simulations necessary to determine the transfer functions are performed with the FDTD method. We limit the construction of the alternative model to replace only the simulation of step 2 of the initial problem (the most expensive step).

The multiplication of these transfer functions with the input field values can estimate in a short time the value of the three component field at the output point. These transfer functions can be used again to study several positions of the human body model around the vehicle.

B. Application and results

The study is done at the frequency of 60 MHz. The transfer functions are firstly determined using three FDTD simulations in accordance to figure 5. Three simulations are executed for the three electromagnetic field components. The parameters of these simulations are given in Table III.

The transfer functions are then used to calculate the field

TABLE III
SIMULATION PARAMETERS FOR THE CALCULATION OF TRANSFER FUNCTIONS

Time step	14,626 ps
Spatial resolution ($dx \times dy \times dz$)	(8 × 8 × 8) mm
Observation time	200 ns
Simulation time	(220 × 3) min

TABLE IV
RESULTS OF DG-FDTD SIMULATIONS

	DG-FDTD values	Substitution values	relative difference
$ E_x $	0.00025917	0.00025696	0.8526 %
$ E_y $	0.00056803	0.00056529	0.48189 %
$ E_z $	0.00069921	0.00069296	0.89392 %
$ E_{total} $	0.0009374	0.00093047	0.73927 %

TABLE V
COMPUTATION TIME WITH THE DG-FDTD APPROACH

	One position	Ten positions
Step one (160 mm)	0.56 min	5.6 min
Step two (8 mm)	356.48 min	3564.8 min
Total	357.04 min	3570.4 min

TABLE VI
COMPUTATION TIME WITH THE SUBSTITUTION PATTERN

	One position	Ten positions
Calcul of transfer Functions (8mm)	748 min	748 min
Step one (160mm)	0.56 min	5.6 min
Step two (8mm)	0.2 min	2 min
Total	748.76 min	755.6 min

components at the center of the eye in response to an illumination resulting from a complete simulation of the scenario (160 mm description).

Table IV compares the results of the classic DG-FDTD simulation (160 to 8 mm) with results of the substitution model. The combination of DG-FDTD and substitution model provides results with an error less than 1%.

The Tables V and VI show the computation time obtained with the two approaches for the study of one body position in the environment and for the study of ten body positions.

These results indicate that the use of substitution model presents an interest in terms of time calculation for the study of multiple positions. The study of a new position requires only 0.54 min.

V. APPLICATION ON THE ADDRESSED SCENARIO

Combination of DG-FDTD method and substitution model is applied on the selected scenario. The study is done at the frequency of 60 MHz. 888 positions are considered around the vehicle.

Figure 6 presents the orientations of the body in the space and a field cartography. The cartography represents the module

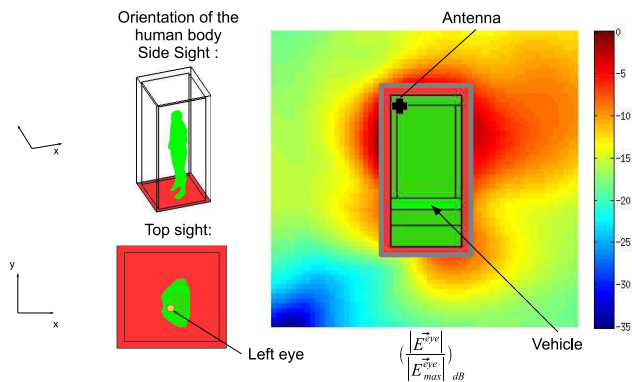


Fig. 6. Results normalized using the combination of methods.

of the electric fields in the center of the left eye when the body is located in the environment for 888 positions around the vehicle. This cartography is normalized to its maximum.

VI. CONCLUSION

This paper proposes to combine the DG-FDTD method with a substitution model to process a highly multiscale and variable problem for a numerical dosimetry. The combination of these two techniques is applied on a scenario and provides quick results with a very good accuracy.

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