Fast Estimate of Thermal Responses of Biological Bodies due to RF Exposure

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***Abstract*— A fast approach is proposed for estimating the thermal responses of biological bodies due to RF exposures. The approach is based on ANN models. The results obtained from the fast approach agree well with those calculated directly from the thermal solver. The advantage is that the approach is fast and is not dependent on the biological body and mesh sizes.**

I. INTRODUCTION

Penne's bio-heat transfer equation [1][2] has been commonly used for calculation of thermal responses of biological bodies due to RF exposure. The finite difference method is generally applied to discretize the bio-heat equation, and the generalized thermal boundary condition is used to truncate the space. The resulting iterative update equations in the time domain can be obtained to calculate the temperature rise. The spatial meshes in the update equations naturally match those used for the FDTD method. Therefore it is straightforward to integrate the thermal solver with an EM solver such as XFdtd®. Due to the high fidelity meshes of human models and the iterative procedure, however, the thermal solver is usually not quite efficient. Thus, it is recommended to find a fast method for predicting the thermal responses of biological bodies due to the RF exposure.

In this paper, a fast estimate method is proposed, implemented, and tested. The thermal solver in XFdtd is first enhanced and validated by published data, and is then used for generating samples required for the proposed fast approach. The thermal responses generated from the fast approach are compared with those calculated directly by the thermal solver.

II. PROPOSED APPROACH

The procedure of the fast approach is summarized in Figure 1. The fast approach works like a quasi-analytical solution. To achieve this, first we need to determine the inputs and outputs of the analytical function. The thermal solver is then applied to generate a minimum set of samples which are used to train an artificial neural network (ANN) model. After the ANN model is well-trained by the samples, it can generate many thermal responses within one second.

III. VALIDATION

To validate the thermal solver, the 1D layered tissue model as shown in Figure 2 is simulated. Figure 3 shows the initial and final temperature distribution along the z-direction for the 1D layered tissue model using various thermal boundary conditions. It can be seen that the results agree very well with the published data [3][4].

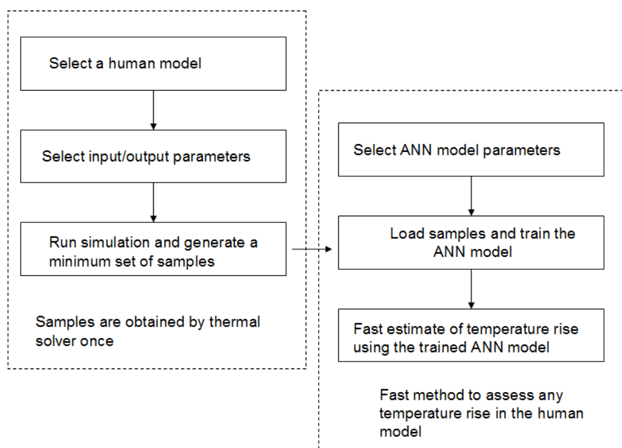


Figure 1 Block diagram of the procedure of the fast approach

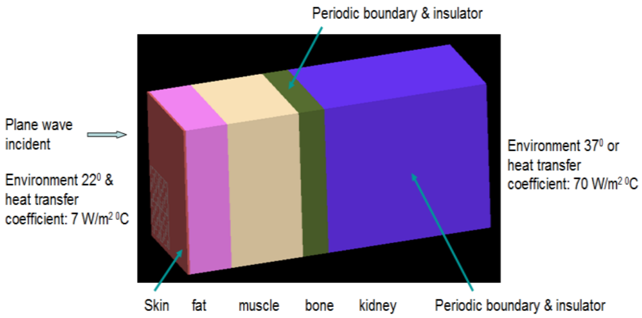
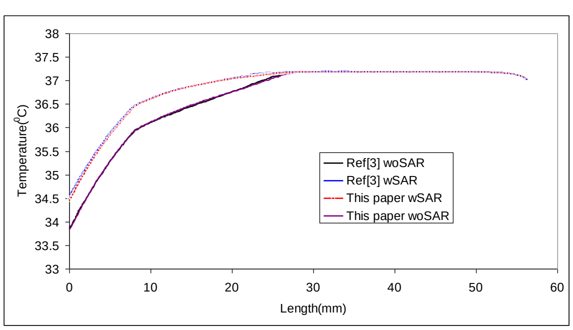


Figure 2 1D layered tissue model with electromagnetic and thermal boundary conditions

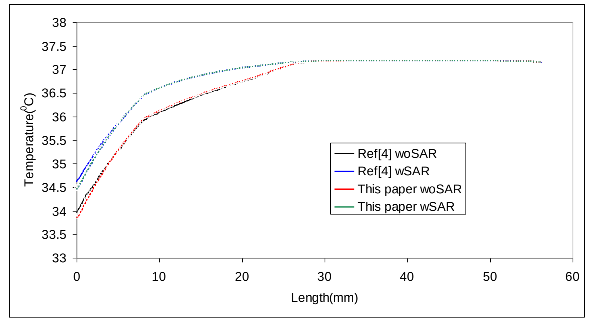
IV. TEST RESULTS

The details of the test example are described as follows. The human head is excited by a plane wave of 450 MHz as shown in Figure 4. The inputs include the RF power, angle of incident wave, and RF exposure time. For this test case, a total of 7x5x42 samples are used, including seven phi angles (0^0, 15^0, 30^0, 45^0, 60^0, 75^0 and 90^0), five power levels (1, 3, 5, 7 and 9 watts), and forty-two time points. The theta angle equals 90^0 and the plane wave is phi-polarized. The outputs are the whole body (whole head) averaged, the tissue (white matter) averaged, and the point (a point in the right eye vitreous humor) temperature rise. Figure 5 shows the results of the ANN model versus the thermal solver for whole body averaged, tissue averaged, and point temperature rise of the head phantom. It can be seen that the agreement for each case is very good.

The fast approach is convenient and efficient to demonstrate the thermal responses versus various factors. Figure 6 shows the whole body averaged, tissue averaged, and point temperature rise versus angle and power, respectively. It can be observed that the whole body and tissue averaged temperature rises do not vary much with the angle of incidence, but the point temperature rise is very sensitive to this angle. This is because the point in the right eye vitreous humor may be blocked by other tissues due to the change of incident angle. It can also be seen that all the temperature rises including whole body, tissue averaged, and the point are almost linearly increased when the RF power of the incident wave increases, but the increase rates are different.



(a) constant environment temperature 37^0 at the upper z-direction



(b) heat transfer coefficient 70 $Wm^{-2}\,{}^0C^{-1}$ at the upper z-direction

Figure 3 Initial and final temperature distribution along z-direction for the 1D layered tissue model using various thermal boundary conditions, (a) constant and (b) heat transfer coeffiecient, compared with the published data

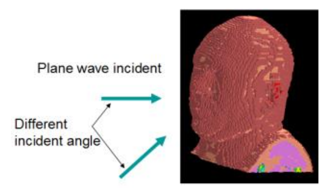
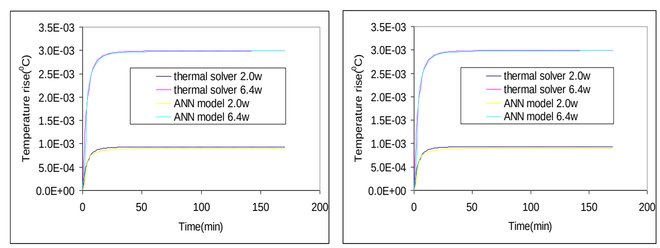
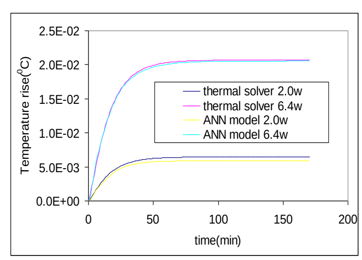


Figure 4 Head phantom excited by a plane wave

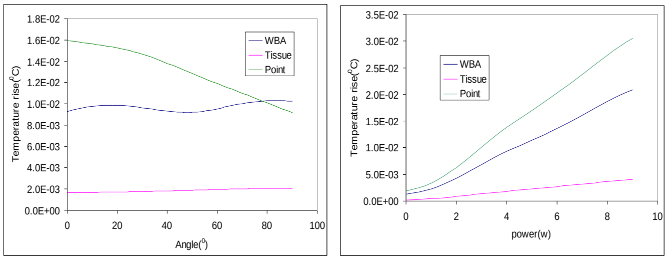


(a) whole body (whole head) (b) tissue (white matter)



(c) point (in the right eye vitreous humor)

Figure 5 The results of the fast approach versus thermal solver for whole body (whole head) averaged, tissue (white matter) averaged, and point (in the right eye vitreous humor) temperature rise of the head phantom



(a) Trise vs. angle (b) Trise vs. power

Figure 6 Whole body averaged, tissue averaged, and point temperature rise at 100 minutes for (a) 4.0 watts versus angle and (b) 40^0 angle versus power calculated from the fast approach

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