Analysis of the distribution of specific absorption rate induced by five plane waves with a fast and new method in Visible Human

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Abstract

In this paper, we analyze the variation of Whole Body Specific Absorption Rate (WBSAR) induced in Visible Human by five plane waves with random direction of azimuth angles, amplitudes and phases. A new and fast numerical method presented in a first paper [1] is used to perform this study. Considering a finite set of 36 azimuth angles, the Latin Hypercube Sampling is used to design an experiment plan. Two distributions of amplitudes are used to design the plan and the different results of WBSAR for each case are compared. The response Y (WBSAR) is modeled as a combination of input parameters influencing the exposure. Using input parameters, the azimuth angles described by the surface projected and the WBSAR, a regression estimates the model coefficients. The influence of inputs variables of the function is analyzed.

1. Introduction

The increase in wireless technologies, the public ask more and more information about adverse health effects on the electromagnetic waves. The assessment of exposure in real environment is important. Electromagnetic fields reference levels derived from the basic restrictions has defined by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [2] to protect people avoid health effects. In reality, the waves are coming from random directions because they interact with the obstacles. Due to the many configurations of exposure in real environment, assessing accurately the SAR is difficult. In a previous study [3], we statistically analyzed the exposure of a child phantom named Thelonious to 5 random plane waves. A fast numerical method to assess the multiple exposure of the Visible Human (VH) is used to perform this study. We study the exposure of the VH to 5 plane waves with Log-Normal distributed amplitudes, phases and azimuth angles having discrete uniformly distribution between 0° and 360°. But in this case, the azimuth angles are chosen in a finite set $\varphi = \{(\varphi_i)_{i=1,..36}, \varphi \epsilon [0°, 350°], \varphi \epsilon N\}$ of 36 elements. Using a Latin Hypercube Sampling [4], we assess the distribution of WBSAR. The exposure to 5 plane waves coming from various directions will is assessed and the influence of the field's parameters is analyzed. A simply model to approach the WBSAR is proposed.

2. Materials and methods

2.a Materials

Numerical models of human have been developed to perform numerical dosimetric study and assess accurately the exposure. The variability of the exposure depends on the human extern and intern morphology [5] [6]. Our study is to asses the distribution of WBSAR induced by five plane waves with an experiment plan. This study has been conducted with the Visible Human (figure1). The VH [7] is a heterogeneous phantom of 1.86-m height and 105-kg body mass. We used the dielectric properties of the human tissues.

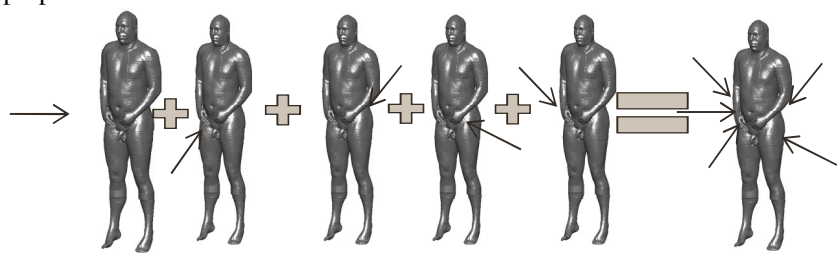

Figure 1: Visible Human exposed to five plane waves

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Due to the reflections and diffractions, the waves are propagated along multiple paths. The electric field can be modeled as a sum of random multiple plane waves (1).

$$\overrightarrow{E_{inc}}(\vec{r}) = \sum_{n=1}^{5} A_{inc,n} \exp\left(i\alpha_{inc,n} - i\vec{k}_{inc,n}.\vec{r}\right) \vec{u}_{E_{inc,n}} \quad (1)$$

As described in [8,9] the average number of incident plane waves is five. The electric field has a vertical polarization. The amplitude has a Log-Normal distribution. The azimuth angles are chosen in a finite set of 36 azimuth angles and these azimuth angles follow a discrete Uniform distribution between 0° and 360°. The phases have a continuous uniform distribution between 0° and 360°. The waves are propagated in the horizontal plane.

2.b Method

The Finite-Difference Time-Domain (FDTD) code is used [10] to assess the power absorbed by the phantom. To simulate the propagation in free-space and to avoid spurious reflection at the boundary of the limited numerical domain, absorbing boundary conditions have to be imposed in our in-house code using the Uniaxial Perfectly Matched Layer (UPML) [11]. The method to compute the new WBSAR is explained in [1]. To be compared, the values of whole body SAR are normalized to the incident power computed analytically as the square of root-mean-square (RMS) of the each plane wave amplitudes. To optimize the simulation to perform, a Latin Hypercube Sampling is used to design an experiment plan.

3. Latin Hypercube Sampling

The Latin Hypercube Sampling (LHS) is a particular Monte Carlo Sampling with more precisely. It is a constrained Monte Carlo sampling scheme [12]. The Latin hypercube sampling is used to have a precise response with few simulations. We plan is designed considering 3 parameters, azimuth angles, amplitudes and phases of the plane waves. Each factor can take 5 random values according to the number of plane waves. The azimuth angles are chosen in a finite set of 36 azimuth angles and they follow a discrete Uniform distribution. The phases follow a continuous uniform distribution between 0° and 360°. The study has been conducted with two distributions of amplitudes. The first plan has been designed with amplitudes having a Log-Normal distribution and the second plan with amplitudes follow uniform distribution between 1 and 2 V/m. The influence of the distribution of the amplitudes on the WBSAR is analyzed in the section 4.

4. Results

Firstly, we design an experiment plan according to a linear regression model having 15 inputs (i.e 5 amplitudes, 5 azimuth angles, 5 phases). 17 simulations of WBSAR corresponding to 5 different set of azimuth angles have been computed equal to16 coefficients of the regression plus 1. This number of output is necessary to approximate the coefficients. For each set of 5 random azimuth angles, 20 sets of 5 phases having continuous uniform distribution and 5 amplitudes (Log normal and uniform) are designed to obtain WBSAR. So, 17*20=340 WBSAR values have been computed for each case. The cumulative distributions functions (fitted by a Gaussian) of 340*2 values of WBSAR are represented in Figure2.

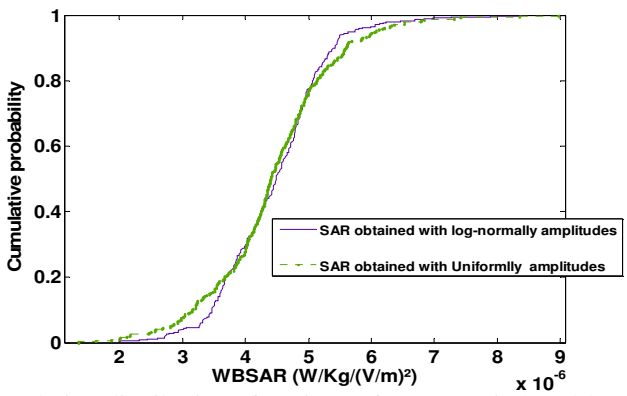

Figure 3: Cumulative distributions functions of WBSAR induced by 5 plane waves having two random azimuth angles, amplitudes and phases

The first cdf plotted by the continuous line represent the cdf of WBSAR obtained for the experiment plan designed with the amplitudes log-normally distributed. For these 340 samples, the variation coefficient of WBSAR (defined as the ratio of the standard deviation to the mean) is of 20%. The KS test shows that the WBSAR samples follow, with a P-value of 95%, a Gaussian law. The other cdf in dash represente the 340 values of WBSAR obtained for an exposure to uniform amplitudes. In this case, the variation coefficient of WBSAR is 22%. The distribution follows also a Normal Law. The difference of the two means is below than 14%. We can conclude that in this case of exposure at five random plane waves the distribution of the amplitudes have not a much influence on the WBSAR distribution.
We also analyzed for 17 different set of 5 fixed azimuth angles, the simultaneous influence of the amplitudes and the phases on the WBSAR. We also analyzed for 17 different set of 5 fixed azimuth angles, the influence of the amplitudes and the phases on the WBSAR. In Fig.4, we plot for each set of 17 configurations in terms of incidences, the variation of WBSAR corresponding to the 20 sets of 5 amplitudes having Log-Normal distribution and 5 phases uniformly distributed.

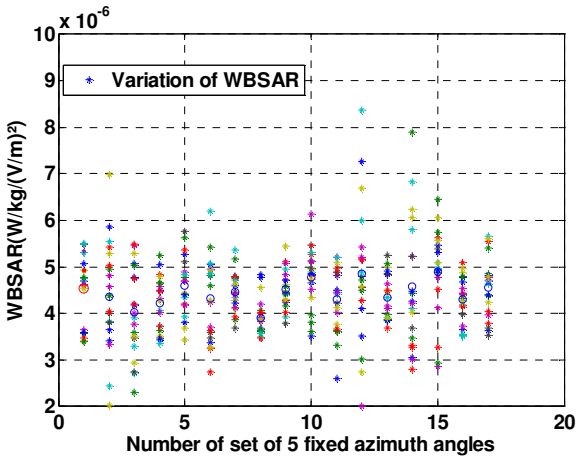

Figure 4: the influence of amplitudes (log normally) and phases on the WBSAR for fixed azimuth angles

We show that for a fixed set of 5 azimuth angles, the maximum variation of WBSAR around the mean value can be of 30%. We obtained approximately the same variation if we consider that the amplitudes and the phases have uniform distribution. In this case the maximum variation of WBSAR around the mean value is 27%. This result confirms also that the difference of the amplitudes do not influence considerably the result of exposure. In fact, in the case of multiple exposure the fading is due to the phase's recombination.
A model (5) based on the relationship between the WBSAR and the surface projected related to incidence among and ellipsoid parameters have been proposed and analyzed. The surface projected is modeled by this equation (4):

$$surface = \pi \frac{H}{2} \sqrt{\frac{L^2}{2} \cos(\varphi)^2 + \frac{P^2}{2} \sin(\varphi)^2} \quad (4)$$

We assume that the projected surface of the VH is approximately the same as the projected surface of an ellipsoid [13]. The parameters of the ellipsoid have been chosen so that the height (H), width (W), and thickness (P) coincide with those of the VH model. We consider that the WBSAR is a function of the surface projected $S(\varphi_i)$so the azimuth angles.

$$Y_i = \beta_0 + \sum_{i=1}^{5} \beta_i S(\varphi_i) + \varepsilon \quad (5)$$

The first regressions do not provide a good estimation of coefficients according to the Student test. Due to the phase's recombination, it will be very difficult to find a rigorous model to assess the WBSAR induced by multiple 5 plane waves. But, we found that the vector of errors or residuals (5) defined by ε=WBSAR-WBSAR^, has a Normal distribution with an error of 0. In fact, it is possible to assess a distribution of WBSAR induced by 5 plane waves and showed in [3]

5. Conclusion

This study proposes an approach to assess statistically the multiple exposures with a discrete set of azimuth angles and to compare the influence of the field's parameters notably the amplitudes on the WBSAR.
We have shown a new method to compute WBSAR values in reduced time using a discrete set of incident azimuth angles. We analyzed the influence of the amplitudes and the phases on the WBSAR induced by 5 plane waves. We also proposed a regression model to assess a distribution of WBSAR. This paper shows that we can perform with an experiment design a rigorous statistical analysis of exposure in real environment.

7. References

1. T. Kientega, E. Conil, A. Hadjem, A. Gati, E. Richalot, M.F. Wong, O. Picon, J. Wiart, A new approach to assess the Specific Absorption Rate induced by multiple plane waves at 2.1 GHz Wiart Submitted at Eucap Roma 2011

2. ICNIRP, "International Commission on Nonionizing Radiation Protection guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)," *Health Phys*, vol. 74, no. 4, pp. 494–522, 1998.

3. T. Kientega, E. Conil, A. Hadjem, A. Gati, E. Richalot, M.F. Wong, O. Picon, J. Wiart, Assessment of the SAR induced by multiple plane waves exposure, Annales des telecommunications, accepted

4 .Kenny, Q. Y., Orthogonal Column Latin Hypercubes and Their Application in Computer Experiments, Journal of the American Statistical Association 93, No. 444, 1430-1439,1998

5.A. El Habachi, E. Conil, A. Hadjem, E. Vazquez, M. F. Wong, A. Gati, and J.Wiart, "Statistical analysis of whole-body absorption depending on anatomical human characteristics at a frequency of 2.1 GHz," Phys. Med,2010

6. Conil. E, Hadjem. A, Lacroux. F, Wong. MF and Wiart J "Variability analysis of SAR from 20MHz to 2.4GHz for different adult and child models using FDTD" Phys. Med. Biol. 53 1511-1525, Apr. 2008

7.M. J. Ackerman. Accessing the visible human project D-Lib. Mag. [Online]. Available: http://www.nlm.nih.gov/research/ visible/visible_human.html, , Oct.1995

8. Vermeeren G, Joseph W, Olivier C, Martens L. Statistical multipath exposure of a human in a realistic electromagnetic environment. Health Phys 94(4):345–354. 2008.

9. Kalliola K, Sulonen K, Laitinen H, Kiveks O, Krogerus J,Vainikainen P. Angular power distribution and mean effective gain of mobile, vol. 20, no. 3, Apr. 2002

10.Taflove A and Hagness S 2005 Computational Electrodynamics: The Finite-Difference Time-Domain Method, 3rdedn (Norwood, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification, IEEE Std. 802.11, 1997.

11. X. Berenger J
"A perfectly matcher layer for the absorption of electromagnetic waves J. Comp. Phys. 114 185 -200", 1994

12. McKay, M. D., Beckman, R. J. and Conover, W. J. (1979). A comparison of three methods for selecting values of input variables in the analysis of output from a computer code, Technometrics 21, pp. 239–245.

13.Conil E, Hadjem A, Gati A, Associate Member, IEEE, Wong MF, Senior Member, IEEE, and Wiart J, Senior Member, IEEE;"Influence of Plane-Wave Incidence Angle on Whole Body and Local Exposure at 2100 MHz" Accepted on IEEE transaction on electromagnetic compatibility, 2010