Surrogate model based on Polynomial Chaos of Indoor Exposure Induced from a WLAN Source

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Abstract

This paper presents a statistical analysis of indoor exposure induced from a WLAN source. A surrogate model based on Polynomial Chaos method is proposed. The analyzed scenario consists of an anatomical model located in an unknowing position of a room of 3x4m² and a source located in a random position but near to the wall room. A computer experimental design based in a LHS method is proposed to cover at best the entire possible configurations. To calculate the exposure, a hybridize method combining the spherical wave description and the FDTD numerical method is used. 250 simulations had been performed and two surrogated models are presented.

1. Introduction

The increase of the wireless communication networks and the diversity of usages, involves a risk perception concerning human exposure to Electromagnetic Field (EMF). So many studies have focused on the exposure assessment [1]. The exposure to Radio Frequency (RF) sources is quantified using the Specific Absorption Rate (SAR) that defines the power absorbed per unit mass of tissues. The SAR is assessed by measurement and/or simulations. Concerning to simulations, the Finite Difference Time domain (FDTD) is the numerical method often used.

The simulations are performed using heterogeneous human body models that are exposed to RF sources located far or near from the body. In the case of the far source (e.g. base station, macrocell antennas), the exposure is often performed using a plan wave and Huygens box [2][3][4][5]. When the source is close to the body, both human body and RF source are modelled [6][7].

Today, wireless access points such as femtocells or small cells are located at intermediate distances, between those of very close sources and far sources. In this case, a method using the equivalence principle is proposed. The field emitted by the intermediate source is described using the spherical wave expansion (SWE) and then this description is hybridized to the FDTD method [1][8].

The aim of this communication is propose a surrogate model of the indoor exposure induced by an intermediate source (i.e. Wi-Fi WLAN source) as approximation of the computational model (the hybridize approach, SWE and FDTD). A realistic scenario is analyzed. An anatomical model is located in an unknowing position of the room, and an intermediate source turns around near to the room walls but in a random position.

2. Exposure assessment

To assess the exposure induced by sources located at intermediated sources, the SWE and FDTD hybridized method is used. In fact, the field emitted by the source cannot be assessed with the usual plane wave hypothesis because of the possible proximity of the source, and modelling the source is impossible because of memory computation constraints.
This method consists on calculate the incident field using the SWE. The SWE consists in expressing the Electromagnetic fields (EMF) by a combination of spherical waves in an orthogonal basis of the EMF space [9]. Then the field is applied to compute the Huygens Box in the Cartesian system and then to perform the FDTD simulation.

Equation 1 and 2 present the electric $\vec{\mathrm{E}}(\mathrm{r},\theta,\varphi)$ and magnetic $\vec{\mathrm{H}}(\mathrm{r},\theta,\varphi)$ fields.

$$\vec{\mathrm{E}}(\mathrm{r},\theta,\varphi)=\frac{\mathrm{k}}{\sqrt{\eta}}\sum_{\mathrm{s}=1}^{2}\sum_{n=1}^{N}\sum_{m=-n}^{n}Q_{smn}\vec{\mathrm{F}}_{smn}(r,\theta,\varphi) \quad (1)$$

$$\vec{\mathrm{H}}(\mathrm{r},\theta,\varphi)=\text{-ik}\sqrt{\eta}\sum_{\mathrm{s}=1}^{2}\sum_{n=1}^{N}\sum_{m=-n}^{n}Q_{smn}\vec{\mathrm{F}}_{3-smn}(r,\theta,\varphi) \quad (2)$$

Where r is the radius between the observation point and the sources, θ is the elevation angle, φ is the azimuth angle. k is the free space propagation constant, η is the specific admittance. N is the number of the modes, Q_{smn} is the wave coefficients, $\vec{\mathrm{F}}_{smn}$ is the wave function of index *s (TE or TM)*, order *m* and degree *n*. The Q1 and Q2 coefficients are obtained by measurements using the MVG® "StarLab" near field measurement system [10].

Figure 1 shows the coordinates (O,x,y,z), where the origin (O) is at center of the Huygens Box. The FDTD domain is considerably reduced to approximately the same as that of the Huygens box.

In this paper the source is a WLAN operating at 2400 MHz and the human body model is "Eartha" [11]. This is a girl body model of 8 years old, having weight and height respectively equal to 30.7 kg and 1.36 m.

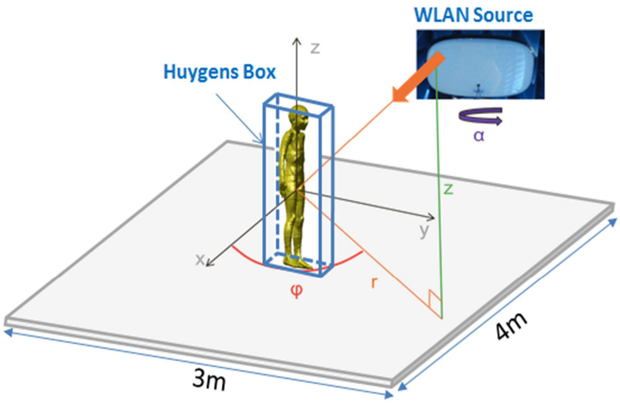


Figure 1. Posible configurations exposure

3. Computer Experiment

The exposure scenario is based on five independent parameters with a uniform distribution over their ranges. The possible variations are summarized in the Table 1. The first parameter is linked to the source horizontal position source around the room wall; the source is located next to the walls at 5cm. Second parameter parameterizes the vertical position of the source. The third, fourth and fifth parameters are driving to the anatomical human body model positions. The model is located in a X, Y random position at 55 cm from the wall. The last parameter, θ, manages the anatomical model rotation on its axis.

Parameter	Range
Source position	[0-13.59]
Source height	[0.25 2] m
Eartha position X	[0.55 3.45] m
Eartha position Y	[0.55 2.45] m
Angle	[0.1 359]

Table 1. Input Parameters Range

The combination of all these possible configurations can induce complex variations of the human exposure. In this study a LHS (having the maximum minimum distance between samples [12]) design experiment has been used to select the input parameters of 250 simulations.

4. Surrogate Model

A surrogate modeling based on the Polynomial Chaos Expansions (PCE) [1, 8, 13] can be used. In summary, PCE consists in the approximation of the system output in a suitable finite-dimensional basis $\{\psi_i\}$ made of orthogonal polynomials. For computational purposes the polynomial expansion is truncated after P terms:

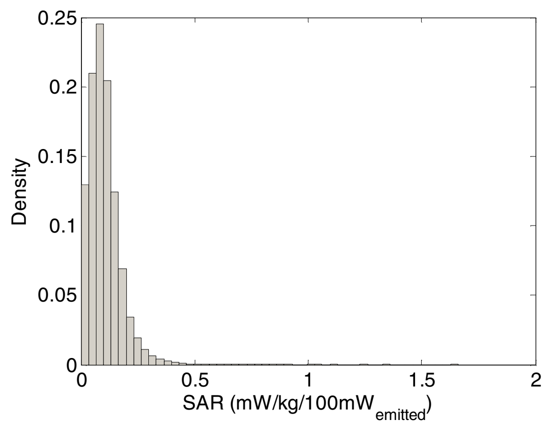
$$Y = M(X) = \sum_{0}^{P-1} \beta_\alpha \psi_\alpha(X) + \varepsilon = \hat{Y} + \varepsilon \qquad (3)$$

where Y is the system output (Whole Body SAR, and brain SAR), X is the random input vector made of the input parameters linked to the configurations described in II.B, $\psi_\alpha(\boldsymbol{X})$ are the polynomials belonging to the basis $\{\psi_i\}$ β_α are the coefficients to be estimated and ε is the truncation error.

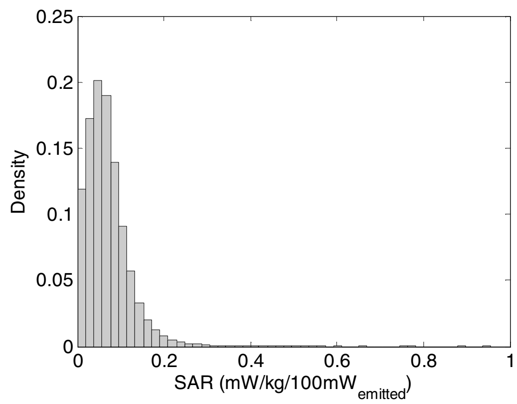
The coefficients β_α of the Truncated PCE $(\hat{Y})$ can be obtained by least-square regression with respect to a series of N observations $\{y^{(1)}, y^{(2)} .. y^{(N)}\}$ calculated by SWE-FDTD deterministic method with respect to an experimental design $\{x^{(1)}, x^{(2)} ..x^{(N)}\}$. The model $\hat{Y}$ is acceptable when the predictions are in line with the target that can be assess using a leave-one-out (LOO) cross-validation [14]

5. Results

Based on the results of 250 simulations, two surrogate models have been built, one for the whole body SAR and a second for the brain. The two models are acceptable, the whole body model has a Q2 factor of 90% and the brain is 88%. The Figure 2 shows the probability density function obtained for the two models. The mean whole body SAR is 0.103 mW/kg/100mW emitted and the mean brain exposure is 0.069 mW/kg//100mW emitted.



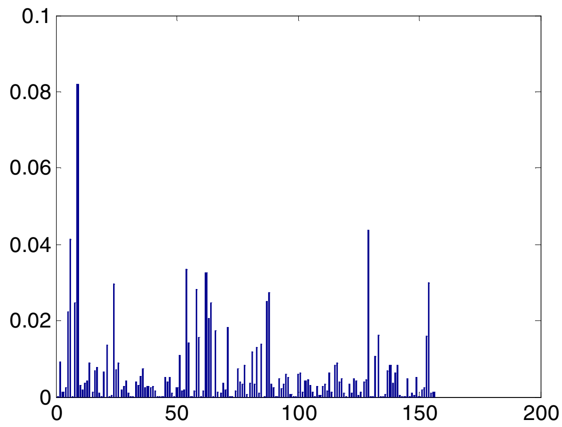
(a) Whole Body



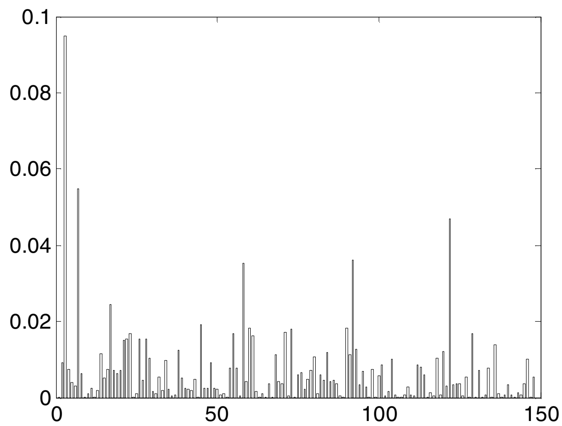
(b) Brain

Figure 2. Probability distribution function for two models

The Figure 3 shows the signature [15] of these surrogate models that are given by the coefficients and the polynomials involved in the model. Comparing whole body and brain model, we observe that the distribution is quite different reflecting the difference between the brain and the whole body exposure.



(a) Whole Body



(b) Brain

Figure 3. Polynomial coefficients

7. Conclusions

A statistical analysis of the exposure induced in indoor by a WLAN source is presented. The exposure is assessed using the SWE and FDTD hybridized method. A planning experiment of 250 simulations has been conducted. For a WLAN source emitting 100mW in a room of 3x4m the mean whole body exposure is 0.103 and the mean brain exposure is 0.069 mW/kg. A sensitivity analysis will be performed.

7. References

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