Near-field Estimation using a Reduced Basis Expansion of Induced Modes in a Human Head Model from Equivalent Sources

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Abstract

A new approach to evaluate near-field induced by a cellular phone in a human head model using an E-field expansion into a basis is proposed. This technique is first based on Huygens principle using equivalent currents on a closed surface which makes it valid for any cellular phone. Then, using Singular Value Decomposition, the generated induced E-field by any cellular phones would be expanded with the orthonormalized modes excited by the equivalent sources in a human head model. Finally, we estimate the error reconstruction of E-field using a reduced number of modes.

1. Introduction

In wave interaction with human bodies, the evaluation of near electric field can be of great interest for verification of compliance of radiofrequency base stations, or of cellular phones [1]. In this last case where we are focused in, the most accurate technique to measure the field induced in a Specific Anthropomorphic Mannequin (SAM) is to use a robot scanning all the volume equipped with a probes. Unfortunately, this technique takes a long time to estimate the Specific Absorption Rate (SAR) of a cellular phone deduced from the E-field square induced in the SAM and physical parameters (conductivity and density). Techniques, using data interpolation, or parametric approach to reconstruct E-field have been proposed to reconstruct E-field from a scan on a reduced number of measurements [2]. More recently, a technique was studied by using integral formulation of equivalence principle in a flat phantom to expand the E-field [3]. In this paper, we propose a new technique suited to a curved phantom as SAM, using an equivalence principle to expand the induced E-field of any cellular phone into modes. The induced modes ensure an optimal decomposition i.e. with a reduced number of modal coefficients.

2. Equivalence Principle

The proposed technique starts with an equivalence principle. Any cellular phone enclosed by a surface S can be described from a field point of view by an equivalent current on surface S (Fig.1).

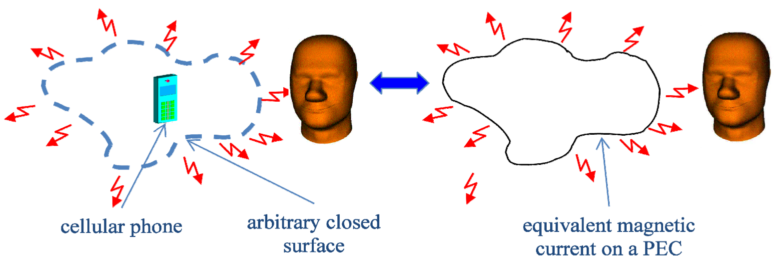

Fig.1: Equivalence theorem applied with a SAM phantom

We are interested in the E-field outside the arbitrary closed surface, and more precisely inside the human head model. There exists a distribution of equivalent currents over the surface emitting the same induced E-field in the human head model than the devices. Instead of using both electric and magnetic surface currents; we use only magnetic surface current on a Perfect Electric Conductor (PEC) [4]. According to this, the equivalence current produces the same field in region 2 (**E_2, H_2**) than the device under test (DUT).

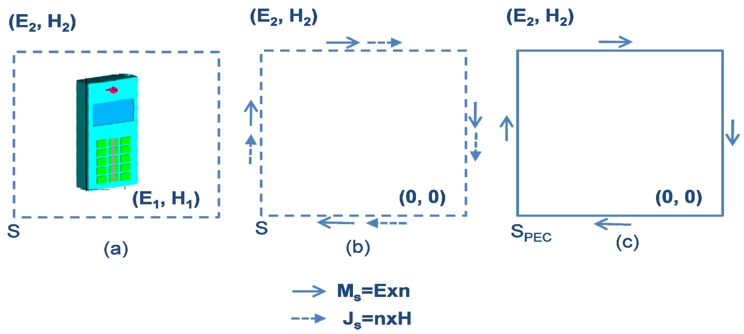

Fig.2: The induced E-field is the same in (a), (b), and (c)

This equivalence principle (Fig.2-c) is applied on a FDTD grid. The surface enclosing the cellular phone corresponds to a surface mesh with the edges supporting the electric field. It means that each edge *i* of the mesh surface is a voltage corresponding to the magnetic current M_i, while the others edges are short-circuited.

The device illuminating the phantom can be then replaced by a distribution of magnetic current, and the E-field induced by the DUT in the media can be written as a linear combination of induced field by these equivalent elementary sources in the same media (3).

$$E_{DUT} = \sum_{i=1}^{N} c_i E(M_i) \tag{1}$$

N is the number of edges on the Huygens surface surrounding a device, $E(M_i)$ is the induced field by the equivalent source M_i at the grid points *i* and c_i the corresponding coefficients.

3. A reduced decomposition based

The equation (1) can be rewritten in a matrix formulation (2):

$$E_{DUT} = Mc \tag{2}$$

Where $M = \left(E(M_1) \quad \ldots \quad \mathrm{E}(\mathrm{M}_N) \right)$ and *c* is the vector of the coefficients c_i.

The minimum number of degrees of freedom, corresponding to the optimum number of basis function to expand E_{DUT} can be reached by a Singular Value Decomposition (SVD) of the matrix *M*. The SVD factorises the rectangular and complex matrix *M* into three matrices (3).

$$M = UDV^* \tag{3}$$

The columns of *V* form a set of orthonormal "input" basis vector directions for *M* corresponding to the excited sources on the closed surface and the columns of *U* form a set of orthonormal "output" basis vector for *M* corresponding to the induced singular modes in the media by the excited sources. The element s_i of the diagonal matrix *D* contains the *N* decreasing singular value and corresponds to the weight of each associated singular modes.

In our study case, we use a set of *N*=6468 (the number of edges on the surface S) elementary equivalent sources to create the basis of decomposition. After a singular value decomposition (5), we may obtain an optimal reduce basis of decomposition which can be set to a number of modes equal to the rank of M.

The E-field E_{DUT} can be then decomposed into a reduced number of modes U (4, 5).

$$E_{DUT} = \sum_{i=1}^{n} d_i U_i \tag{4}$$

$$E_{DUT} = Ud \tag{5}$$

With d the modal coefficient and *n* the number of significant modes. Some of them are presented in figure 3 associated to their respective excited equivalent sources on the closed surface in figure 4.

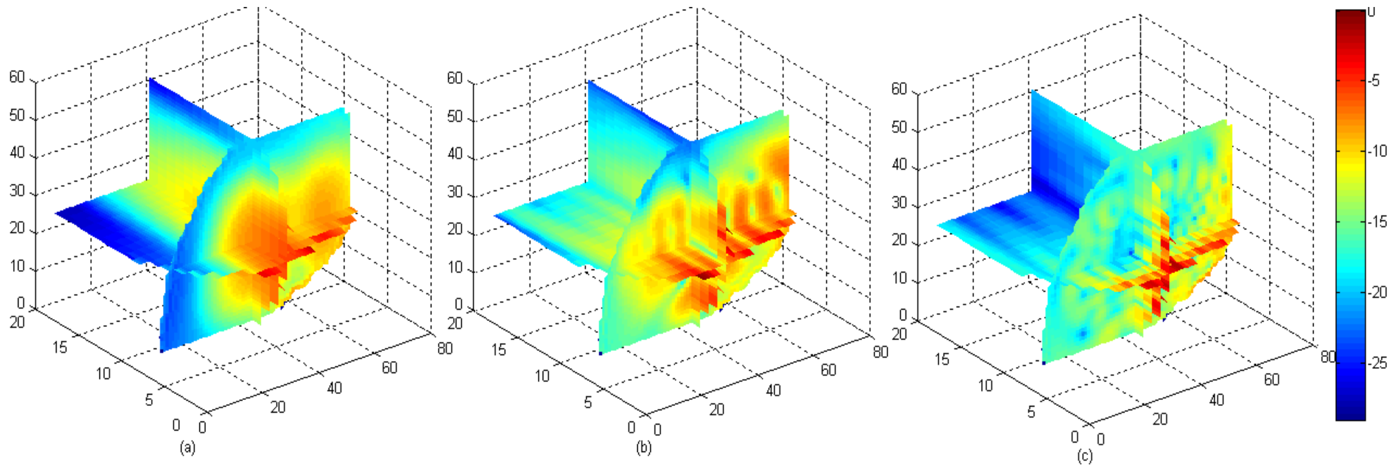

Fig.3: Representation in amplitude (dB) of orthonormal modes: 1st (a), 30th (b), and 200th (c).

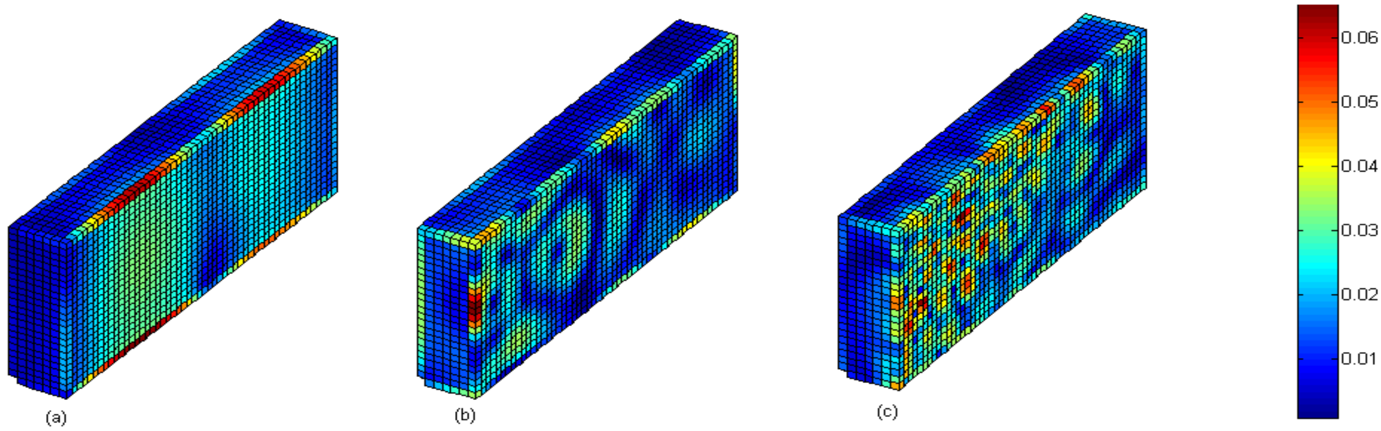

Fig.4: Representation in amplitude (dB) of excited equivalent sources on the closed surfaces generating the 1st (a), 30th (b), and 200th (c) modes.

4. E-field decomposition

We worked in a case of induced E-field E_{DUT} in a volume inside a human head model at the vicinity of a cellular phone emitting at 1800 MHz. All the orthonormal modes were generated in the same condition of exposure, and we study the decomposition of this induced E-field into these modes. In figure 5 we represent E_{DUT} and its signature in the orthonormal basis function U using (7).

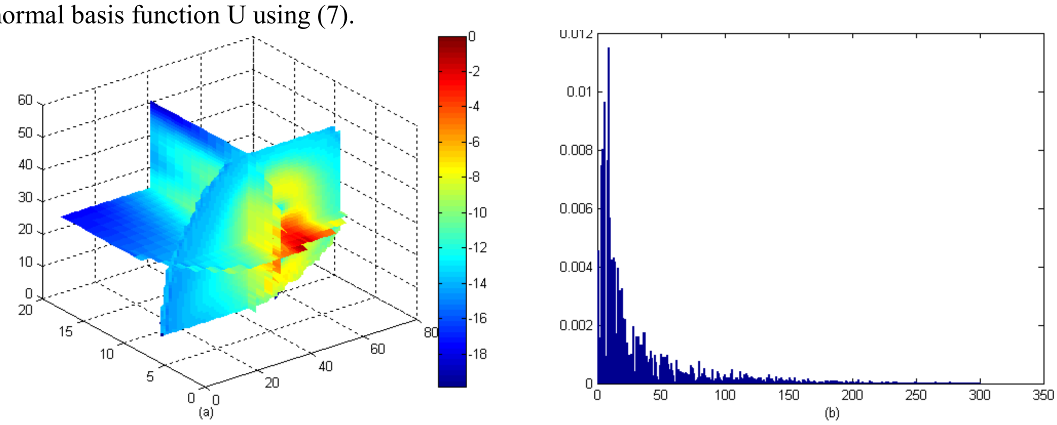

Fig.5: Amplitude (dB) of E_{DUT} representation in the volume of study (a), and amplitude of coefficient (b).

As we see, we maybe don't need to recover E_{DUT} using all modes. In figure 7, we have the L^1 and L^2 relative error nom (8) versus the number of modes.

$$L^p(d_{DUT}) = 100 \times \frac{\|U.d_{DUT} - E_{DUT}\|_p}{\|E_{DUT}\|_p},\ p = 1,2 \qquad \|E\|_p = \left(\sum_i |E_i|^p\right)^{1/p},\ p = 1,2 \tag{8}$$

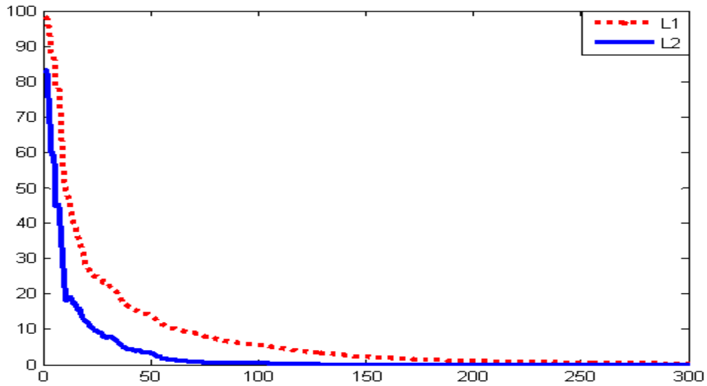

Fig.7: relative error norm in % L1 and L2.

5. Conclusion

In our approach, we are able to know physically the number of significant modes from where we can expand an induced E-field on a human head model. This knowledge is of great importance in the case where sparse measurements are envisaged to reconstruct the volumetric data inside a curved phantom.

6. Acknowledgments

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7. References

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