The Human Body Modelled by Canonical Geometric Shapes for the Analysis of Scattered E-fields

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Abstract **─** The objective of this paper is to propose a simplified model of a human body to be used in electromagnetic problems involving high frequency field scattering. Canonical geometric shapes, analytically described, represent the body. The accuracy of the model was tested comparing the field scattered by the simplified body representation with the one scattered by a more realistic phantom. At first, the influence of anatomical details of the body was analysed, comparing the electromagnetic field reflected by a realistic human head with the backscattering of spheres and of an ellipsoid. A second test concerns the human body, modelled by sphere, parallelepiped and cylinders. In this case, the possibility of reconstructing a wideband pulse scattered by the whole body with the superposition of pulses scattered by its separated parts was demonstrated. Both analyses were carried out in the frequency range 3-5 GHz using a full wave numerical simulator.

Index Terms **─** Computationally body model, on body model, scattering.

I. INTRODUCTION

The optimal design of contact-less monitoring systems of the main human physical and physiological activities involves analysis of the interactions between the human body and electromagnetic (EM) waves [1,2]. These studies are widely carried out by means of computer simulations, which are well suited for a careful study, but involve the use of detailed human body models [3-5]. Most EM solvers perform an automatic meshing on the simulated objects, choosing an arbitrary number of cells per wavelength.

Starting from the S-band, the human body becomes an electrically large structure, and several cells per wavelength are required to model the target and to decrease the numerical dispersion error [6-8].

This implies simulations that are highly memory and time intensive, depending on the body model and the frequency of interest [9-11].

Several research works have focused on modelling simplified human body mannequins to reduce the computational burden. Perfectly electric conductor cylinders were employed to reproduce the body [12] or to predict the effect of people on indoor propagation channel [13]. The validation of the models was carried out with experimental investigations, comparing the signal attenuation between the transmitting and the receiving units and antennas located on the simplified human model and on a real target. Nevertheless, to our knowledge, very few studies have been done to assess the characteristics of a body model to be used in scattering problems, guaranteeing accuracy and computational efficiency at the same time. This issue is dealt with in the paper, and an efficient simplified human model is accurately analysed.

In detail, a human body represented by canonical geometrical shapes is proposed. It exhibits many advantages: 1) all the elements are analytically described; 2) it is simple and easy to implement; 3) it is very flexible, because all postures can be represented; 4) movements and animations are possible; 5) it is effective in a wide frequency range.

The accuracy of the model was tested by comparing the waveforms of EM pulse, reflected by a realistic human body and by the proposed model.

A human head and the effect of anatomical details such as nose, mouth and ears were evaluated. A further

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investigation was extended to the whole body, analysing the possibility of retrieving the field backscattered by the whole body as superposition of the field reflected by separated body parts.

II. HUMAN FACE REPRESENTED BY CANONICAL GEOMETRIC SHAPES

A previous work [2] pointed out that the most proper frequency range to detect the breathing rate or body activities during real-time monitoring is 2-6 GHz. In this frequency range, approximate skin depth is lower than 1.5 cm. Therefore, a body representation with an accurate knowledge of internal tissues is useless, because only a thin external layer is involved in the evaluation of the scattered field.

Another aspect concerns the representation of external details of the body, such as the nose, mouth and ears. The great variability of such anatomical details from one individual to another makes an excessively accurate modelling ineffective.

In this section, the relevance of the anatomical details for the evaluation of EM backscattering was analysed, both in time and in frequency domain. The EM field reflected by the head of a Specific Anthropomorphic Mannequin (SAM) was compared with the backscattering of canonical geometric shapes, using a full wave numerical tool (CST Microwave Studio [14]). The chosen targets are shown in Fig. 1.

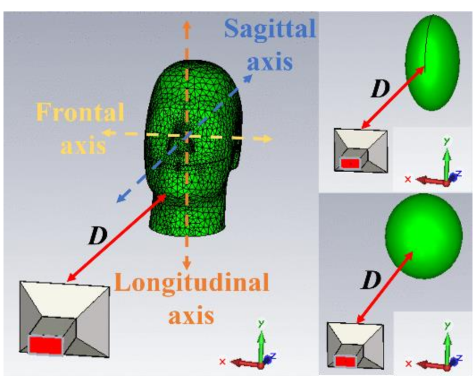

Fig. 1. Geometric configurations implemented in CST Microwave Studio: head on the left side; spheres of different radii and an ellipsoid on the right side.

More precisely, four spheres and one ellipsoid were analysed. The first sphere has a radius r = 109 mm, providing a volume equivalent to SAM's head. The other spheres have a radius of 80 mm, 126 mm and 132 mm, which correspond to the dimensions of the head, along the frontal, sagittal and longitudinal axes respectively. The ellipsoid has dimensions of 80 mm x 126 mm x 132 mm. The head and solids were filled with a homogeneous dielectric material with the same properties as the skin (relative permittivity εr = 42, and conductivity σ = 3.6 S/m [15]). Both targets were placed at a distance of D = 1.5 m from a horn antenna along the z-direction. The excitation signal is a modulated Gaussian pulse, generated by the CST Microwave Studio's time domain solver, whose spectrum is in the range 3-5 GHz. The wave travels in free space along the z-direction and the electric E-field is polarized in the y-direction. Figure 2 and Fig. 3 show the E-fields reflected by the solids and by the head, observed at 1 m along the z-axis, in time (TD) and frequency (FD) domain respectively. For a better comparison among the waveforms, the cross-correlation r_{xy} was evaluated between the E-fields diffracted by each solid (y) and by the head (x). Table 1 reports the absolute value of the maximum amplitude of the backscattered electric fields, and the results of the corresponding r_{xy} in both TD and FD.

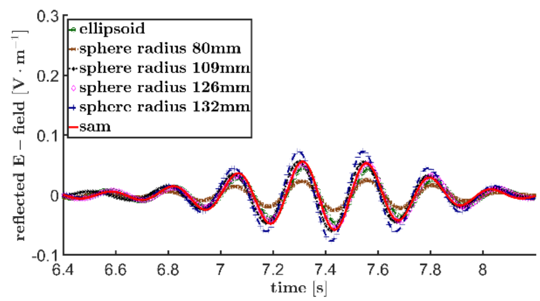

Fig. 2. E-fields backscattered by the head and the solids, observed in time domain.

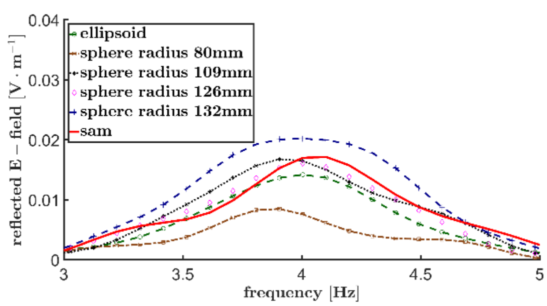

Fig. 3. E-fields backscattered by the head and the solids, observed in frequency domain.

We may appreciate that the sphere (r = 109 mm) with equivalent volume to the head provides a response that best fits the realistic situation.

Moreover, the reflected waves were normalized to the maximum peak value and correlated, in order to observe how their distortion depends on the scattering surface. All the chosen geometric shapes present a correlation of 0.99. The result proves that the representation of the anatomical details can be neglected in the range of a few GHz.

Table 1: Maximum field intensity and cross-correlation between the E-field waveforms diffracted by the spheres, the ellipsoid and the head

Target	E-field [V/m]	TD: r_{xy}	FD: r_{xy}
SAM	0.058	1	1
Sphere (r = 80mm)	0.025	0.44	0.46
Sphere (r = 109mm)	0.059	0.99	0.98
Sphere (r = 126mm)	0.055	0.95	0.95
Sphere (r = 132mm)	0.077	0.74	0.74
Ellipsoid	0.047	0.82	0.83

III. NUMERICAL RESULTS OF THE E-FIELDS SCATTERED BY THE HUMAN BODY PARTS

The results achieved in the preceding section were extended to the whole body, analysing the possibility to retrieve the electric field backscattered by the whole body as superposition of the electric fields backscattered by separated body parts. The error due to the approximation of neglecting mutual electromagnetic coupling between body parts was estimated to quantify the trade-off between accuracy and computational efficiency.

The human body was modelled as a collection of sphere, cylinders and parallelepiped to reproduce head, chest, arms and legs, whose dimensions are defined according to those of a realistic body. The height of the human model is 1.68 m and each part is characterized by the dielectric properties of the skin. Furthermore, the mutual coupling among body parts was neglected.

The analysis was carried out with the same simulation set-up described in the previous section. Figure 4 shows the E-fields scattered by each body parts and observed at the distance D of 1.5 m in the time domain. As expected, at this position, the E-field reflected by the chest is greater than any other E-fields, because of its dimension and flat surface.

The comparison between the E-fields reflected by the total body E_{r1} (mutual coupling considered) and by its individual parts E_{r2} (mutual coupling neglected) was examined both in time and in frequency domain.

The results are shown in Fig. 5 and Fig. 6, respectively. The cross-correlation pointed out a similarity between the two curves equal to 0.85 in both domains. Since the waveforms are quite similar, we can infer that the different field contributions due to each body part are combined with the proper time delay; the peak amplitude difference is due to the numerical accuracy, and is not significantly affected by the assumption of negligible mutual coupling among body parts.

To highlight this aspect, further simulations were performed to evaluate the influence of spatial discretization.

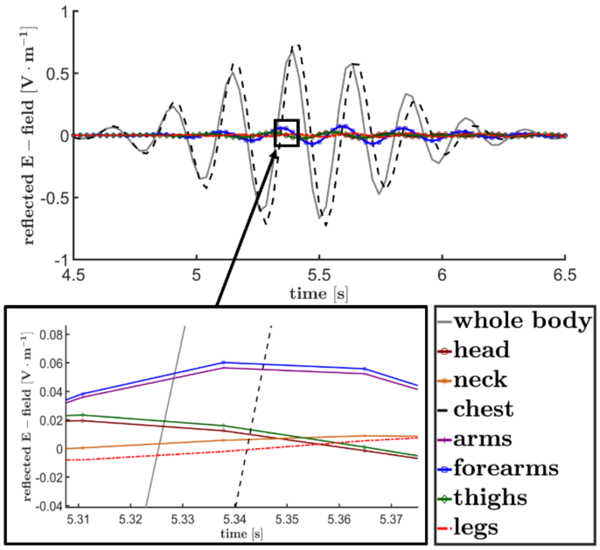

Fig. 4. Electric fields backscattered by individual elements of the human body (time domain).

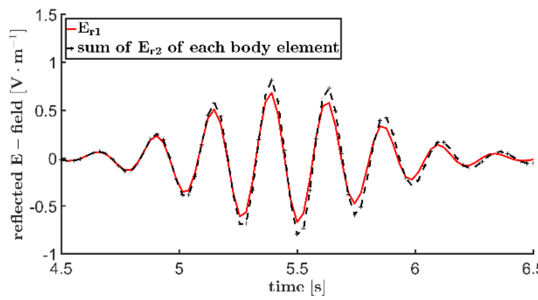

Fig. 5. E-field scattered by the whole body phantom and the sum of the E-fields scattered by each body part (time domain).

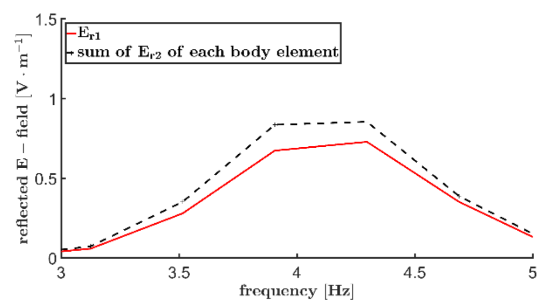

Fig. 6. E-field scattered by the whole body phantom and the sum of the E-fields scattered by each body part (frequency domain).

The total calculation times required to simulate separately the body parts as a function of the spatial resolution, and the cross-correlation coefficient r_{xy} between the resulting curves mentioned above, are shown in Table 2.

The computer employed for the simulations has the following characteristics: processor Intel(R) Core(TM) i5-5200 CPU, 8GB RAM DDR4, graphics card NVIDIA GEFORCE 820M 1800MHz.

Table 2: Analysis of the numerical accuracy as a function of spatial discretization

Resolution (Cells per Wavelength)	Calculation Time	Cross-Correlation
λ/8	26 h, 14 m, 28 s	0.83
λ/10	45 h, 34 m, 25 s	0.85
λ/12	87 h, 50 m, 39 s	0.89

As expected, a finer grid provides better accuracy in the computation of the peak values and improves the correlation coefficient, but the waveform is not significantly affected by this parameter and no distortion can be appreciated.

IV. CONCLUSION

In this paper, we have demonstrated that in the S and C bands a simplified model of a human body compared to realistic model can be efficiently employed to evaluate the reflected electric fields. The correlation coefficients were analysed to compare in time and in frequency domain the realistic and the approximate solutions. The results outline that from a computational point of view, the body elements can be replaced with homogeneous geometric solids, and the anatomical details, as well as the mutual coupling among body parts, can be neglected. The simplified model proves to be efficient, light in terms of computational burden, and sufficiently accurate to analyse the interactions between the human body and the EM fields.

REFERENCES

[1] A. Rahman, Y. Ishii, and V. Lubecke, "UAV-radar system for vital sign monitoring," *ACES Journal*, vol. 1, no. 5, 2016.

[2] V. Petrini, V. Di Mattia, A. De Leo, P. Russo, V. P. Mariani, G. Manfredi, G. Cerri, and L. Scalise, *Domestic Monitoring of Respiration and Movement by an Electromagnetic Sensor*. Ambient Assisted Living (Springer International Publishing), Basel, 2014.

[3] 3D CAD Browser. http://www.3dcadbrowser.com/3dmodels.aspx?category=1182, accessed May 2018.

[4] REMCOM - VariPose. https://www.remcom.com/varipose-biological-mesh-repositioning-software, accessed May 2018.

[5] Makehuman - open source tool for making 3d characters. http://www.makehuman.org/404.php, accessed May 2018.

[6] R. K. Najm, "Simplified 3-D mesh generator," *ACES Journal*, vol. 6, no. 2, pp. 86-98, 1991.

[7] S. Kashyap and A. Louie, "Surface modelling for EM interaction analysis," *ACES Journal*, vol. 6, no. 2, pp. 38-53, 1991.

[8] C. J. Roy, "Grid convergence error analysis for mixed-order numerical schemes," *AIAA Journal*, vol. 41, no. 4, pp. 595-604, 2003.

[9] H. B. Lim, D. Baumann, and E. P. Li, "A human body model for efficient numerical characterization of UWB signal propagation in wireless body area networks," *IEEE Transactions on Biomedical Engineering*, vol. 58, no. 3, pp. 689-697, 2011.

[10] L. Roelens, S. Van den Bulcke, W. Joseph, G. Vermeeren, and L. Martens, "Path loss model for wireless narrowband communication above flat phantom," *Electronics Letters*, vol. 42, no. 1, pp. 10-11, 2006.

[11] L. Roelens, W. Joseph, E. Reusens, G. Vermeeren, and L. Martens, "Characterization of scattering parameters near a flat phantom for wireless body area networks," *IEEE Transactions on Electromagnetic Compatibility*, vol. 50, no. 1, pp. 185-193, 2008.

[12] Ł. Januszkiewicz and S. Hausman, "Simplified human phantoms for wireless body area network modelling," *9th European Conference on Antennas and Propagation (EuCAP)*, Lisbon, Portugal, pp. 1-4, April 2015.

[13] M. Ghaddar, L. Talbi, and T. A. Denidni, "Human body modelling for prediction of effect of people on indoor propagation channel," *Electronics Letters*, vol. 40, no. 25, pp. 1592-1594, 2004.

[14] CST Microwave Studio, ver. 2017, Computer Simulation Technology, Darmstadt, Germany, 2017.

[15] IFAC - Dielectric properties of body tissues. http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.php, accessed May 2018.

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Her current research interests include the application of numerical modelling to EMC problems, reverberation chamber, and new antenna design such as plasma antennas.

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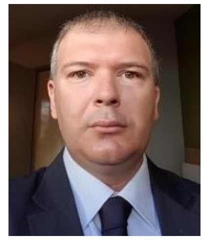

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