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XXXIII Cycle

Modeling of exposure to LF electromagnetic fields of workers in arbitrary posture

Alice CONCHIN GUBERNATI

Supervisors: Prof. Fabio FRESCHI and Prof. Aldo CANOVA

Research context and motivation

RESEARCH CONTEXT

Nowadays workers exposure to low frequency (LF) electromagnetic fields is a source of concern and it is addressed by EU Directives 2013/35/UE. Dosimetric computations are mandatory to assess the respect of limits. For this reason, numerical dosimetry has reached a certain level of maturity, but fast and accurate characterization of exposure in real condition is still challenging for many reasons.

MOTIVATION

Dosimetric computations require the knowledge of the electromagnetic field source model and the exposed worker posture. The classical approach consists in evaluating the source magnetic field and then performing computations with a postured phantom. However, posturing computational phantom is a cumbersome task. My research is oriented towards the study of a different approach based on a change of variable, which allows to carry out all the simulations on an unpostured body model by deforming the source term.

Addressed research questions/problems

Human exposure to LF electromagnetic field problems can be solved by using the finite integration technique (FIT) considering the scalar potential as unknown. The linear system is:

$$\mathbf{G}^{\mathrm{T}}\mathbf{M}_{\sigma}\mathbf{G}\boldsymbol{\varphi} = -\mathrm{j}\omega\mathbf{G}^{\mathrm{T}}\mathbf{M}_{\sigma}\mathbf{a} \quad (1)$$

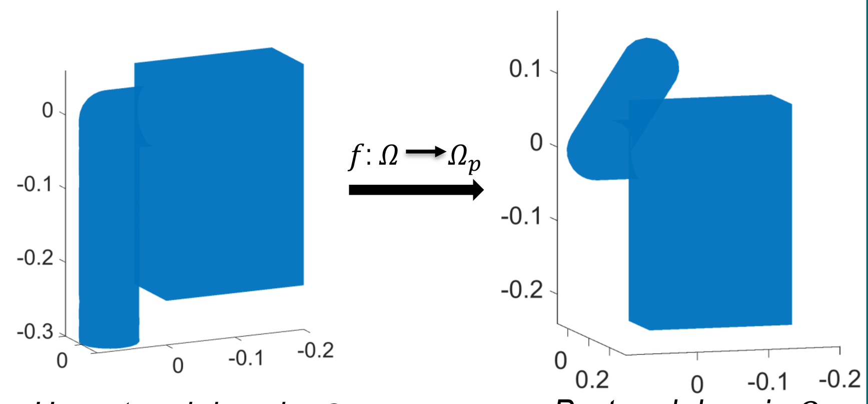
The accurate modelling of the electromagnetic field source and the posture of the exposed worker are required. In these years several realistic anatomical whole-body models of different types of human beings have been developed. However, most of them were only available in the standing position with their arms along their sides, limiting the possibility to study the electromagnetic safety in realistic exposure conditions. For this reason, postured phantom (e.g. sitting one ore the one with outstretched arms) started to be developed. They allowed to carry out the evaluation of human exposure to electromagnetic fields in realistic scenario. However, **posturing computational phantoms is a cumbersome task**, which necessarily introduces some approximations.

Novel contributions

The novel contribution of my research consists in the evaluation of human exposure to low frequency electromagnetic fields on an **unpostured** phantom thanks to a change of variable.

CHANGE OF VARIABLE

- fictitious modification of $\mathbf{M}_{\sigma_\mathrm{p}}$;
- equivalent deformation of $\mathbf{a}_\mathrm{p}$;
- important role played by the Jacobian matrix of the map $f: \Omega \longrightarrow \Omega_p$;
- simplified computations because there is NO posturing step.



Unpostured domain Ω — $f: \Omega \rightarrow \Omega_p$ — Postured domain Ω_p

Adopted methodologies

In the new approach, formulation (1) must be rewritten by considering a new tissue conductivity $\mathbf{M}_{\sigma_\mathrm{p}}$ and a new source term $\mathbf{a}_\mathrm{p}$. Both quantities depend on the Jacobian matrix $\mathbf{J}_\mathrm{p}$ of the map f:

$$\mathbf{M}_{\sigma_\mathrm{p}}^{\mathrm{loc}} = \mathbf{J}_\mathrm{p}^{-1}\mathbf{M}_{\sigma}^{\mathrm{loc}}\mathbf{J}_\mathrm{p}^{-\mathrm{T}} \cdot |\mathbf{J}_\mathrm{p}| \quad ; \quad \mathbf{a}_\mathrm{p} = \mathbf{J}_\mathrm{p}^{\mathrm{T}}\mathbf{a}$$

$\mathbf{M}_{\sigma_\mathrm{p}}^{\mathrm{loc}}$ is locally computed and then the domain-based matrix $\mathbf{M}_{\sigma_\mathrm{p}}$ is assembled in a classical fem-like fashion. The Jacobian matrix is linked to the applied transformation.

The geometric transformations that can be used are translation, rotation, and stretching.

$\mathrm{M}_{\sigma_p}^{loc} = \mathrm{M}_{\sigma}^{loc}$ ➡ translation and rotation

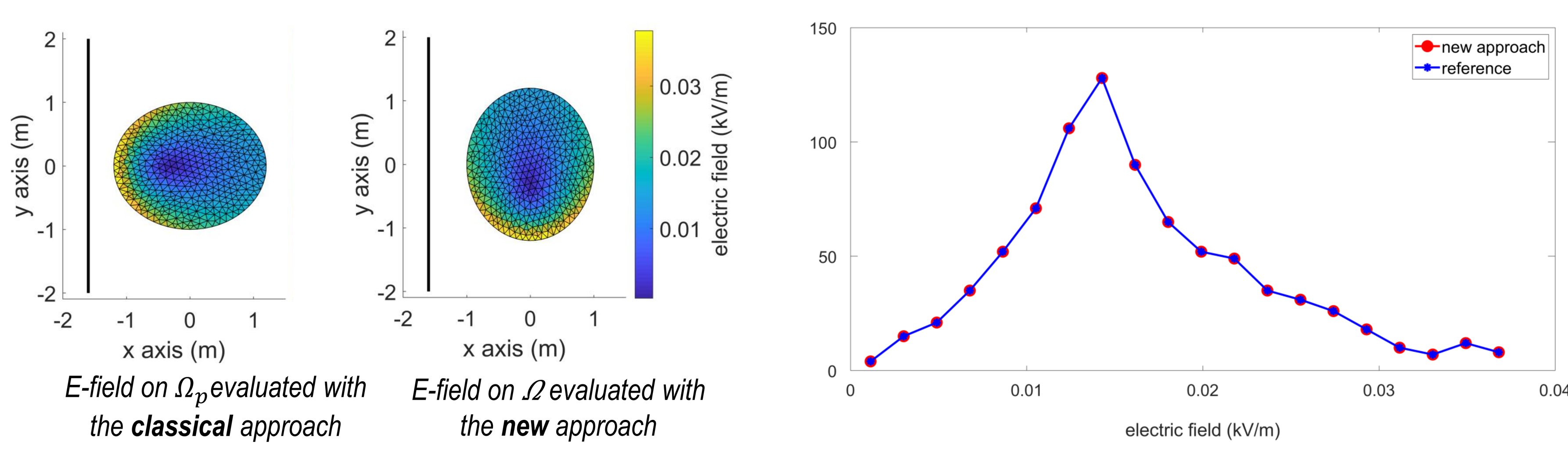
$\mathrm{M}_{\sigma_p}^{loc} \simeq \mathrm{M}_{\sigma}^{loc}$ ➡ stretching

The tissue conductivity not change; only the source term undergoes a transformation.

Submitted and published works

- A. Conchin Gubernati, F. Freschi, L. Giaccone, T. Campi, V. De Santis, I. Laakso, “Comparison of numerical techniques for the evaluation of human exposure from measurement data”, *IEEE Trans. Mag.*, vol. 55, no. 6, 2019
- A. Conchin Gubernati, F. Freschi, L. Giaccone, R. Scorretti, L. Seppecher, G. Vial, “Modeling of exposure to low frequency electromagnetic fields of workers in arbitrary posture”, COMPUMAG 2019, Parigi (Francia), 15-19/07/2019 (accepted for publication on IEEE Trans. Mag.)

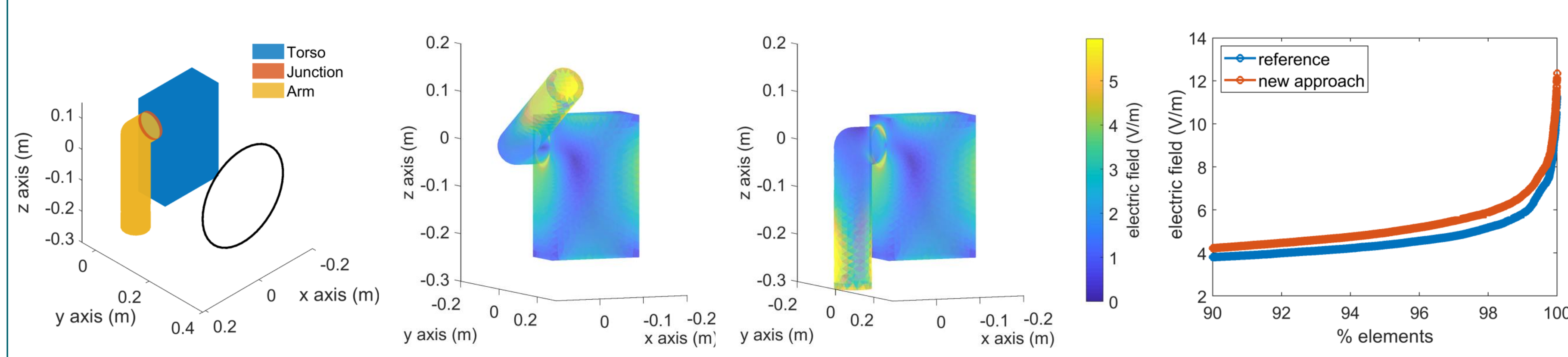
TWO-DIMENSIONAL DOMAIN RESULTS



E-field on Ω_p evaluated with the **classical** approach — E-field on Ω evaluated with the **new** approach

The domain consists in an ellipse with minor semi-axis (*x*-axis)1m long and major semi-axis (*y*-axis) 1.2m long. The tests are based on a 90° clockwise rotation of the ellipse and are performed by considering an infinite vertical wire along *y* as source field placed at a distance of 1.6 m from the center of the ellipse on the left side. The operating frequency is 50 Hz and the current flowing through the wire is 1 kA. The electric field frequency diagram underlines that the results obtained with the proposed method (red curve) are exactly the same as those obtained with the classical approach (blue curve).

THREE-DIMENSIONAL DOMAIN PRELIMINARY RESULTS



Exposure scenario: the simplified phantom — E-field on Ω_p evaluated with the **classical** approach — E-field on Ω evaluated with the **new** approach — Comparison of the induced electric field in the junction

The two approaches have been tested on a simple phantom with a 120° rotation of the arm. A one-loop coil with radius of 15 cm is located 35 cm from the torso and centered in the center of the shoulder . The operating frequency is 50 Hz and the current flowing through the coil is 1 kA. The mesh size is 1 mm in the junction and 15 mm in the torso and arm.

The numerical results of the induced electric field distribution are comparable in the torso and arm, while in the junction there is an overestimation of 11% between the 90th and 100th percentile due to the linear variation of the rotation angle. This overestimation is more than acceptable for a dosimetric assessment.

Future work

Future work expects to apply the proposed method to a more complicated anatomical whole-body model of human being (e.g. Alvar from the Virtual Family) in order to validate the preliminary results obtained on the simplified phantom.

List of attended classes

- 01RISRV – Public speaking (15/02/2018, 5h, SS)
- 02LWHRV – Communication (15/02/2018, 5h, SS)
- 08IXTRV – Project management (15/02/2018, 5h, SS)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (13/03/2018, 6h, SS)
- 01PJMRV – Etica informatica (14/03/2018, 20h, SS)
- 01QORRV – Writing Scientific Papers in English (21/03/2018, 15h, SS)
- 01SHCRV – Unsupervised neural networks (didattica di eccellenza) (09/04/2018, 30h, HS)
- 01SFURV – Programmazione scientifica avanzata in Matlab (13/04/2018, 20h, HS)
- 01RGBRV – Optimization methods for engineering problems (13/06/2018, 30h, HS)
- 01AULLX – Elettrotecnica (04/07/2018, 33.33, HS)
- 01QRNRV – Electromagnetic dosimetry in MRI: computational and experimental methods (04/04/2019, 21h, HS)

EXTERNAL TRAINING ACTIVITIES

- Corso Breve "CST STUDIO SUITE - Low Frequency Training" (09/05/2018, 7h, Milano)
- Corso Breve "Dalla Teoria dei Grafi all'Elaborazione dei Segnali su Grafo", Scuola Nazionale Dottorandi di Elettrotecnica "Ferdinando Gasparini" (13/06/2018, 6h, Roma)
- Corso Breve "Modellistica, simulazione e ottimizzazione di circuiti e sistemi per applicazioni fotovoltaiche", Scuola Nazionale Dottorandi di Elettrotecnica "Ferdinando Gasparini" (19/06/2019, 7h, Viterbo)