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XXXIII Cycle

Advanced computational electromagnetics for field reconstruction

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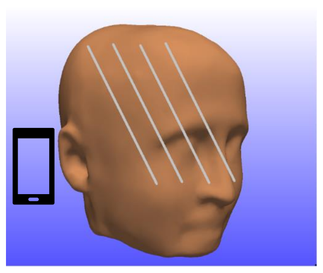
Research context and motivation

- **Radiating devices** are present in all wireless communications devices, which are increasingly being used, e.g. mobile phones.
- The electromagnetic waves radiated from these devices interact with the biological issues of the human body of the human bodies. This is quantified with the **specific absorbing rate (SAR)**.
- The SAR should remain below a certain limit to prevent ionizing radiations from happening in the brain. This is called **dosimetric assessment**.
- The impact of radiative sources on the cerebral activity is not well-known. The measure of the cerebral activity requires the use of an **electroencephalogram setup (EEG)**. This study requires using both an EEG setup while radiating a localized SAR in a part of the brain (collaboration with IMT Atlantique and Télecom Paristech).

- All the previous steps require the use of special radiative sources able to **pre-deform the field to obtain a target field**, e.g. metamaterials-based antennas.

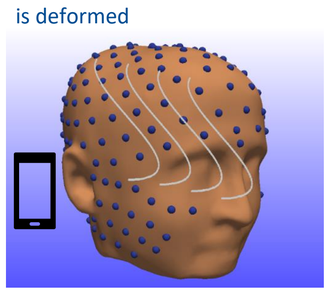
Addressed research questions/problems

1. The field scattered by the mobile is deformed by the electrodes placed on the head during an EEG.



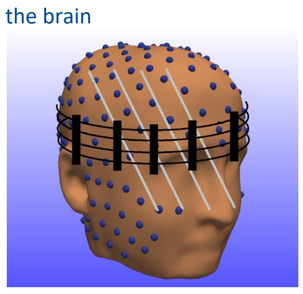
Only the real source is present

The field scattered in the brain is deformed



With the electrodes (EEG) and the real source

The initial field is obtained in the brain



With the electrodes, the fictive sources, and no real source

→ **How to design a source that could pre-deform the electric field to reconstruct the field created by a phone in the presence of the EEG electrodes?**

2. After being designed, the source used to pre-deform the field will be manufactured. Some contraints should be added in the design part to simplify the manufacturing part.

→ **How to constrain the design method to obtain an antenna with feasible material and electric parameters?**

3. The exact positions of the electrode caps on the scalp are not known exactly in practice. Different patients' head lead to different electrode caps coordinates. The uncertainty induced by the position of the EEG caps should be taken into account when modeling the source.

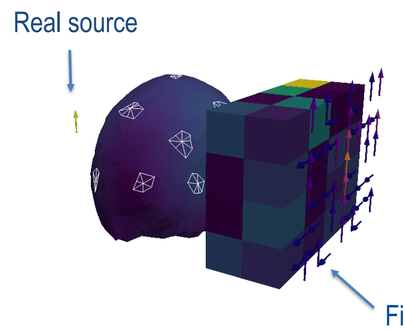
→ **How to propagate an uncertainty on the positions of the electrode caps to an uncertainty of the SAR induced in the head?**

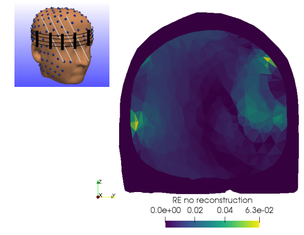
Submitted and published works

- Clément Henry, Adrien Merlini, Lyes Rahmouni, and Francesco P. Andriulli, On the Use of a Full-Wave Solver in the Solution of the Electroencephalography Forward Problem, Abstract, 2019 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Atlanta, U.S.A
- Jade Martínez-Llinàs, Clément Henry, Daniel Andrén, Ruggero Verre, Mikael Käll, and Philippe Tassin, A Gaussian reflective metasurface for advanced wavefront manipulation, Optics Express, vol. 27, no. 15, 2019, pp. 21069-21082
- Xi Cheng, Clément Henry, Joe Wiart, and Francesco P. Andriulli, Uncertainty quantification of RF exposure for assessment of RF impacts on brain activity, Abstract, BioEM2019, Montpellier, France

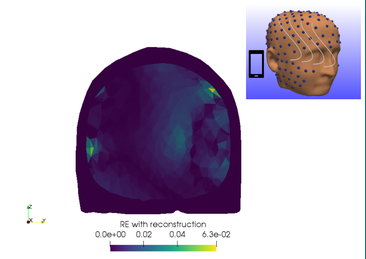
Novel contributions

- Inverse scattering scheme for **source synthesis**



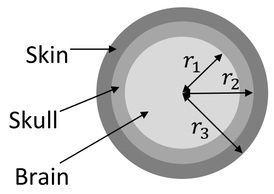


RE before reconstruction

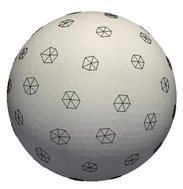


RE after reconstruction

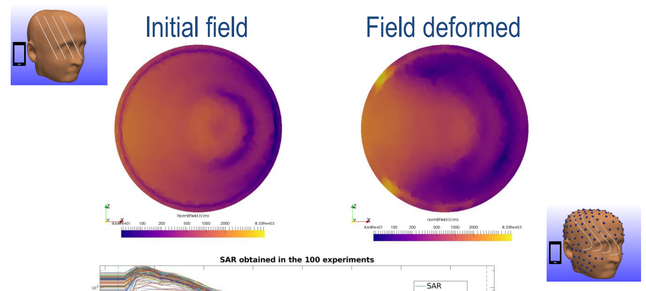
- **Uncertainty quantification** of the positions of the electrode caps on the head



Inhomogeneous dielectric



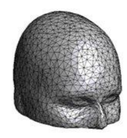
Metallic patches

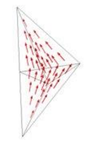


Variation of the SAR for various electrode caps configurations

Adopted methodologies

- The **Hybrid Volume Surface Electric Field Integral Equation** allows to find the total field in inhomogeneous dielectric media and PEC.





- Discretization with **SWG basis functions**.
- **Optimization algorithms** for antenna synthesis: distorbed born iterative method, contrast source inversion, modified gradient method.

$$F(\chi,\omega) = F_{\text{data}}(\omega) + F_{\text{state}}(\chi,\omega) + F_{\text{feasible}}(\chi) = \eta_S \|\boldsymbol{u_s} - \mathbf{G_S}\boldsymbol{\omega}\|^2_{\Gamma_S} + \eta_D \|\chi \boldsymbol{u_i} - \boldsymbol{\omega} + \chi \mathbf{G_D}\boldsymbol{\omega}\|^2_{\Omega_D} + \eta_F \|\chi - f(\chi)\|^2_{\Omega_D}.$$

Future work

- Improve the design of the source by **reducing the number of dipoles** needed and obtaining **more realistic material parameters**.
- Correct the ill-conditioning of this **full wave formulation** at low frequency to enable its use in the **quasi-static regime**.

List of attended classes

- 01QCNKG – Electronic properties of graphene (01/03/2018, 20 hours)
- 01SFVRV – Metamaterials: Theory and multiphysics applications (01/03/2018, 20 hours)
- Microwave Imaging and Diagnostics: Theory, Techniques, and Applications (ESoA (Madonna di Campiglio), 19/03/2018, 30 hours)
- Fast Computing Solvers (IMT Atlantique (Brest), 26/01/2018, 20 hours)
- European School of Antennas (ESoA) - Advanced Computational Electromagnetics (PoliTo, 10/09/2018)
- 01MMRRV – Tecniche numeriche avanzate per l'analisi ed il progetto di antenne (14/03/2019, 20 hours)
- 01RISRV – Public Speaking (26/07/2019, 5 hours)
- 01SHMRV – Entrepreneurial Finance (03/06/2019, 5 hours)
- 01SWPRV – Time management (04/06/2019, 2 hours)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (27/11/2018, 5 hours)
- 01SYBRV – Research integrity (29/07/2019, 5 hours)
- 02LWHRV – Communication (20/05/2019, 5 hours)
- 02RHORV – The new Internet Society: entering the black-box of digital innovation (26/07/2019, 6 hours)
- 08IXTRV – Project management (26/07/2019, 5 hours)

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