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Design of Advance Transcranial Magnetic Stimulation Devices

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Transcranial Magnetic Stimulation (TMS) is a non-invasive technique to stimulate the brain, which has been successfully applied to various psychiatric and medical conditions, such as schizophrenia or Parkinson's disease [1]. Over the last years, it is also becoming a promising treatment for other unexplored neurological disorders, showing a great potential as diagnostic tool when combined with other techniques such as Magnetic Resonance Imaging (MRI) or Positron Emission Tomography (PET). In TMS, strong current pulses driven through a coil are used to induce an electric field stimulating neurons in the cortex.

Most of the standard TMS devices used in clinical practice (such as the figure-of-eight coil) activate mainly superficial cortical areas in the brain, not being able to directly stimulate deep brain regions where exist promising applications for bipolar depression and stress disorder, among others. Moreover, the high coil currents employed in TMS (several kA) can generate a clicking noise originated from the internal deflections of the coil. The levels of noise of this undesired sound can be higher than 120 dB (above recommended auditory safety limits) becoming then a notable safety problem, as it can activate the auditory cortex (affecting so the interpretation of the psychological effects caused by TMS) or cause acoustic trauma. Furthermore, in spite of its growing application, the concurrent use of TMS and functional MRI gives rise to important technical and safety challenges related with the strong interactions between the TMS strong current pulses and the main field of an MRI scanner, which compromise the mechanical stability of the TMS device.

Here a new framework for the design of advanced TMS stimulators is presented. It allows the production of TMS devices with reduced acoustic noise, improved mechanical stability (that can be used for interleaved TMS-fMRI), reduced temperature (which improves patient safety and system stability) and capable of targeting deep areas in the brain with optimal tradeoff between focality and depth. The proposed framework is based on Inverse Boundary Element Method formulated in terms of a continuous current distribution which is posed as a Multiobjective Optimization Problem, which is eventually solved by using a supporting vector formalism [3].

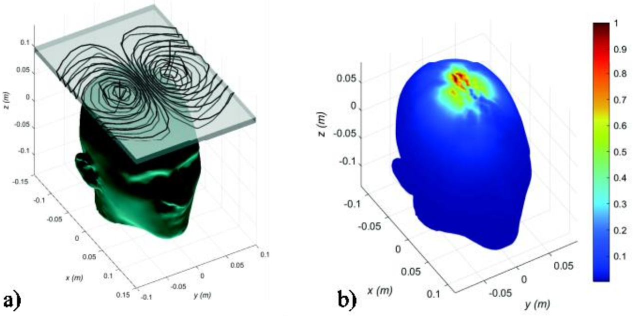

Figure 1. a) Example of a TMS coil with controlled penetration (3 cm), b) Normalized electric field produced by the TMS stimulator at the surface of a human brain.

[1] E.M. Wassermann et al (Eds), "The Oxford Handbook of Transcranial Stimulation," Oxford University Press, Oxford, 2008. [2] Z-D. Deng et al, "Electric field depth–focality tradeoff in transcranial magnetic stimulation: Simulation comparison of 50 coil designs," *Brain Stimulation*, 6, 1, 2013, doi: 10.1016/j.brs.2012.02.005
[3] F. J. Garcia-Pacheco et al, "Exact solutions to $\max\|x\|=1\sum_{i=1}\|Ti(x)\|_2$ with applications to Physics, Bioengineering and Statistics," *Communications in Nonlinear Science and Numerical Simulation*, 82, 105054, 2020, doi:10.1016/j.cnsns.2019.105054.