Uncertainty Quantification in Transcranial Magnetic Stimulation

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Transcranial magnetic stimulation (TMS) is a method for stimulation of neuronal tissue that is used for research in cognitive neuroscience and for treatment of neurological disorders. In TMS, coils placed near the scalp produce magnetic fields that in turn induce electric fields and eddy-currents in the conductive brain tissue. When the magnitude of the spatial gradient of the electric field along a nerve fiber exceeds a certain threshold, an action potential is generated. This trigger mechanism allows neuroscientists to study causal links between stimulated cortical regions and observable behaviors, and clinicians to stimulate mid-dorsolateral prefrontal cortex regions of the brain to treat depression. Unfortunately, the location, volume, and depth of the stimulated region often are strongly affected by the position, orientation, and excitation of the TMS coils, as well as the permittivity, conductivity, and size of the brain. Variability in the TMS setup by the operator and patient-to-patient anatomical variability therefore induce uncertainty in the location, volume, and depth of the stimulated region, limiting the potential of TMS for both research and clinical applications (F. Salinas et al., Phys in med and bio (54), 2009).

In this study, a computational framework for statistically characterizing the region stimulated by TMS is presented. Specifically, given probability density functions (pdfs) of the above uncertain parameters, the framework computes the probability that a cortical region of interest is being stimulated and pdfs for the depth and volume of the stimulated region. To collect this information efficiently, the framework leverages a high dimensional model representation (HDMR) technique that generates parameterized surrogate models for the electric field near the stimulated region. Next, these surrogate models are used in lieu of a computationally expensive electromagnetic simulator while obtaining the statistics of the stimulated regions via traditional Monte-Carlo method. The HDMR technique generates the surrogate models using a series of iteratively constructed component functions. The component functions pertinent to the most strongly interacting uncertain parameters are approximated via a multi-element probabilistic collocation method (Yücel et al., Proc. IEEE Int. Symp. Antennas Propagat., 2012). The accuracy of proposed framework will be demonstrated through the statistical characterization of the stimulated region for commonly performed TMS procedures on concentric spheres and MRI-derived human head models.