Uncertainty Quantification in Specific Absorption Rate Calculation for High-Field MRI RF Coil Design

Xi Wang[1], Shao Ying Huang[2], and Abdulkadir C. Yucel[1]

(1) School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore 639798 (xi002@e.ntu.edu.sg, acyucel@ntu.edu.sg)
(2) Engineering Product Development Department, Singapore University of Technology and Design, Singapore 487372 (huangshaoying@sutd.edu.sg)

Magnetic resonance imaging (MRI) has been extensively used for non-invasive imaging of human tissues and organs in clinical and research settings. In the past decade, there have been substantial academic and industrial research efforts in the development of high field MRI scanners (> 3T) for high-resolution imaging. Such high-field scanners require radiofrequency (RF) coils operated at higher frequencies (>128 MHz), which yield uneven field and temperature distributions in human body. To ensure a safe scan, the specific absorption rate (SAR) in the subject under scan should comply with the high-tier SAR limit from IEEE Std C95.1 -2005 while the computational modeling tools offer a rapid and useful estimation for an evaluation. That said, the fields generated by such RF coils in human tissue are highly sensitive to inter-subject uncertainty (e.g., tissue permittivities, conductivities, anatomical differences), which can significantly change the calculated SAR values and the outcomes of SAR compliance studies. Current commercial or open-source computational modeling tools do not take into account these uncertainties, which can result in significant discrepancies between the computed and actual field and those of the corresponding SAR values. To avoid such discrepancies and ensure safety of the designed RF coils, the computation tools accurately quantifying and incorporating the effects of the inter-subject uncertainties in the simulation results are called for.

In this study, a computational framework incorporating the effects of inter-subject uncertainty in the computed fields and SAR values for head scans at 7T (300 MHz) is proposed. The framework takes the parametric uncertainty in the permittivities and conductivities of head tissues as inputs and provides the means, standard deviations, and probability distributions of fields and SARs on the voxels in the human head. To do that, the framework first generates cheap-to-evaluate surrogate models constructed using a less number of deterministic simulations performed by MARIE, an open-source MRI electromagnetic analysis software (A. G. Polimeridis, J. F. Villena, L. Daniel, and J. K. White, "Stable FFT-JVIE solvers for fast analysis of highly inhomogeneous dielectric objects," *J Comp Phys*, vol. 269, pp. 280-296, 2014). Then it samples these surrogate models with given probability distributions via a traditional Monte Carlo technique to compute the statistics of the fields and SARs. The surrogate models are generated using polynomial techniques (e.g., generalized polynomial chaos expansion and high-dimensional model representation technique) as well as the machine learning techniques (e.g., Gaussian process and extreme learning machine regression). The accuracies achieved by these techniques and the numbers of simulations required by them will be provided in the talk. Furthermore, the application of the proposed framework to the uncertainty quantification in SAR calculation for different RF coils (e.g., high-pass birdcage coil, TEM coil) will be demonstrated in the talk.