Subject-Specific Evaluation of Multi-Channel Receive Coil Arrays by Fast Integral-Equation Method

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Introduction: The performance of high-field receive coil arrays depends on the geometry of coil elements, subject shape, and their relative position. Knowing the actual performance, such as the combined sensitivity and the g-Factor maps, is valuable in post-processing images. Conventionally, subject-specific coil performance was evaluated via measurements. In this work, we present an alternative approach by numerical simulations based on fast integral-equation method and subject models obtained from MRI pre-scans. Results demonstrate the feasibly of performing subject-specific coil evaluations based on pure numerical approaches.

Methods: The surface integral-equation method (SIE) was chosen as the underlining full-wave simulation method [1]. SIE is superb in modeling curved RF coils and numerically more accurate to account for coil/human interactions. The major computational task is to construct and invert the so-called impedance matrix, which is complex, asymmetric and dense. To improve the efficiency, we compressed the impedance matrix by applying a multi-level Adaptive Cross Approximation (ACA) method [2]. The ACA method can be recognized as a column-pivoted Crout algorithm, which compresses matrix blocks on-the-fly without generating them beforehand. Compressed matrix blocks require less computational cost when iteratively solving a matrix, thus greatly speeding up simulations.

In coil array simulations, one usually needs to examine a large number of different coils with a fixed phantom. Since most of the unknowns that need to be solved in SIE are associated with the phantom, one can generate and compress the part of the impedance matrix associated with a given phantom once and save the result for later use. This yields a considerable saving over conventional single-element simulations because the corresponding matrix construction typically consumes half of the entire simulation time. After simulating the electromagnetic field distribution of each element, coil performance can be evaluated by computing sensitivity profiles from magnetic fields and noise correlation matrix from electric fields [1]. Verification of this simulation approach can be found in Ref. [2].

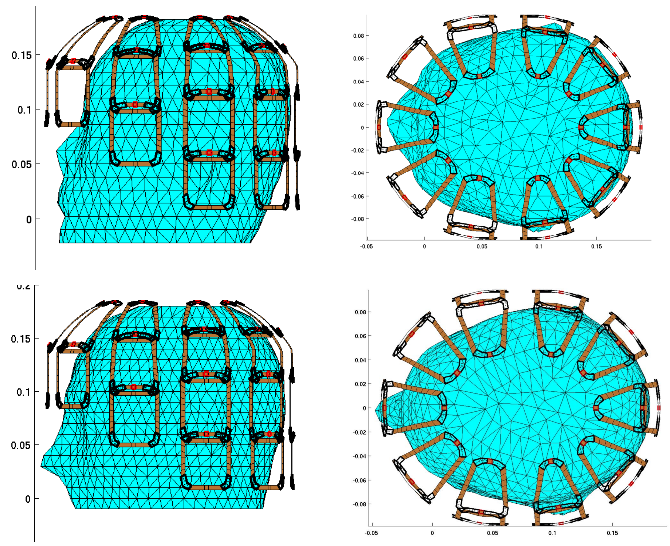

Fig. 2: The 32-channel coil array with the two different subjects.

Results and Discussion: We applied this method to investigate the subject-specific performance of a 7.0 Tesla 32-channel head imaging coil array (Nova Medical, Wilmington, MA). Subject models were obtained by performing a 1x1x2 mm Fast GRE scan on a 7.0 scanner (GE Healthcare, Waukesha, WI) with a Nova birdcage coil (Nova Medical, Wilmington, MA). Scan parameters are as follows: TR = 2.1 ms, TE = 0.9 ms. Total scan time of each subject was 53 seconds. The profile of the head on each axial slice was extracted by image processing, which took a total of one minute on a single CPU for each subject (Figure 1). Subject models were constructed subsequently by stacking all profiles together. Figure 2 shows two subject models within the coil array. The head models were filled with a dielectric that has ε_r = 52 and σ=0.552 S/m, which resembles the white matter at 7.0 Tesla. Thirty two individual simulations were performed with respect to each head model to calculate the B_1 profiles and noise correlation maps. The combined SNR maps and the rate-3 g-Factors maps of the two subjects are shown in Figure 3, which demonstarte quite large differences for different subjects. With two 2.6 GHz dual-core AMD processors, the total simulation time for each subject was 80 seconds and 88 seconds respectively. The actual simulation time depends on the size of the head model and the relative position between coils and the head. Typically, smaller head models and closer proximity result in faster simulations.

Fig 1: Profile extracted from a single axial slice.

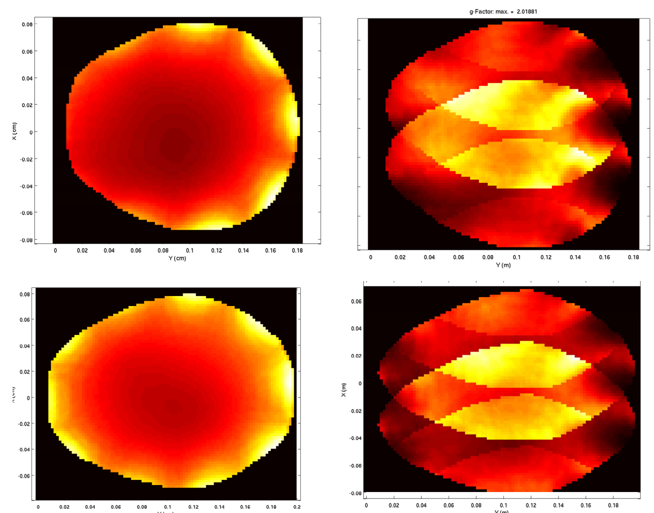

Fig 3: The simulated combined SNR maps (left) and rate-3 g-Factor maps (right) of the two different subjects.

Conclusion: We presented a simulation approach of evaluating the performance of multi-channel coil arrays with respect to actual subjects. With a total of four CPU cores, a 32-channel array can be simulated within one and half minute. Faster performance can be achieved using more CPU cores.

References: 1) Wang and Duyn, Phys. Med. Biol. 51:3211-3229(2006). 2) Wang S., et.al. Proc ISMRM 2009, 507.