FAST MONOTONIC CONVERGENT OPTIMAL CONTROL ALGORITHM FOR 2D RF PULSES MITIGATING B0 AND B1 INHOMOGENEITIES

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Introduction: The use of increasingly strong magnetic fields in MRI improves sensitivity, susceptibility contrast, and spatial resolution in fMRI and spectral resolution in MRS. Albeit these benefits come the challenges of increasing static field (B_0) and rf field (B_1) inhomogeneities induced by radical field susceptibility differences and poorer dielectric properties of objects in the scanner. Two or three dimensional RF pulses are finding more and more interest, because they enable reduced FOV imaging, while still mitigating the B_0 and B_1 non-idealities. In particular RF pulses derived using optimal control (OC) methods have in recent years shown great potential for the ability to handle vast controls and large flip angles [1,2]. Here we present an OC approach, which provides very fast, monotonic convergence of the cost functional even without educated initial guesses [3]. This is essential for in vivo MRI applications. Details and experimental verification of the proposed method for 2D RF pulses was recently published along with a release of the numerical environment. Here we will show with simulations how our proposed algorithm amongst other algorithms compensates B_0 and B_1 inhomogeneities [4,5].

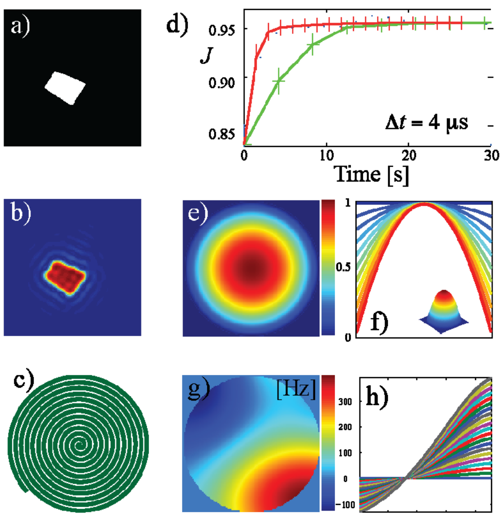

Fig. 1 a) region-of-interest inwhich a $90°_y$ 2D RF is desired; b) the excitation pattern under ideal conditions; c) the spiral trajectory; d) a typical progress of the cost functional for the monotonic approach (red) and a second-order gradient-based method (green), see Ref. 3; e) the most severe B_1 map; f) the diagonal profiles of the 11 B_1 maps tested; g) the most severe B_0 map; h) the diagonal profiles of the 21 B_0 maps tested.

Methods: The 2D RF pulses were designed to excite an arbitrary skewed square (Fig. 1a) in a field-of-excitation of 5.6 cm, resembling that of a pre-clinical 4.7 T system. The underlying slewrate- and amplitude-limited spiral trajectory [6], Fig. 1c, yielded a resolution of 0.9 mm and the pulse duration was 3.5 ms. Firstly, a 2D RF pulse was optimized with ideal conditions (see excitation pattern in Fig 1b) and then subject to permutations of B_0 and B_1 inhomogeneities of increasing severity, Fig. 1e-h. Secondly, 2D RF pulses were optimized for each of the inhomogeneity permutations.

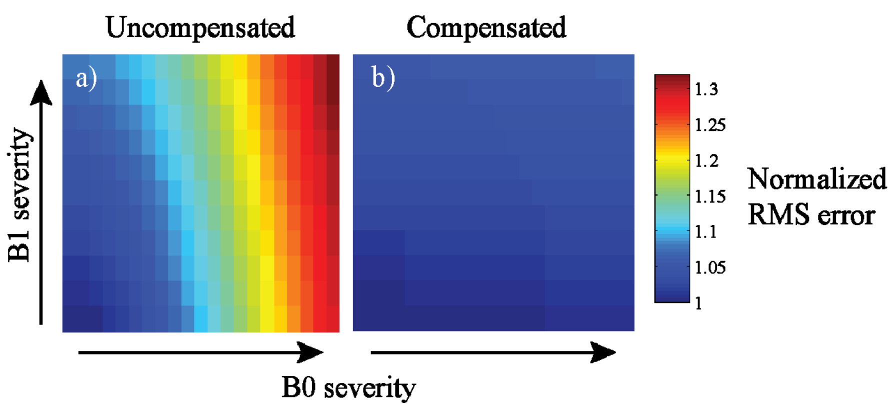

Fig. 2 RMS error maps of the excitation patterns for a) the uncompensated pulse and b) the compensating pulses. Both are normalized to the RMS error of the ideal excitation pattern.

Results: The RMS errors recorded for the uncompensated and compensated excitation patterns are shown in Fig. 2. The lower left corners represent the ideal cases. Moving to the right the offset linewidth becomes broader (up to 250 Hz) and moving upwards the B_1 inhomogeneity becomes more difficult (down to 0% sensitivity in the phantom edges). Inside the region-of-interest the sensitivity spans 9%. The color gradient in the uncompensated case, Fig. 2a, clearly demonstrates the issue of B_0 and B_1 inhomogeneity as the RMS error amounts to more than 32% in this study, and the rather homogeneous result in Fig. 2b demonstrates the ability to mitigate the error to a negligible level of up to 5%.

Conclusion: We have demonstrated numerically that our proposed novel, monotonically convergent algorithm to a satisfactory level is mitigating typical B_0 and B_1 inhomogeneities found on clinical and pre-clinical systems.

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