Direct reconstruction of B1 maps from undersampled acquisitions

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Introduction: Parallel Transmission (PTx) offers more control over B1+ than single channel systems by independently controlling elements of transmit arrays, each with spatially distinct sensitivity patterns. The majority of PTx methods require accurate knowledge of these sensitivities, the measurement of which is often time consuming for the whole array. In this work, we exploit the observation that B1+ maps are smoothly varying in space and are therefore likely to be sparse in several transform domains, a property previously used for receive fields [1]. The B1+ mapping source images contain anatomy and so are less sparse than the B1+ maps themselves. This suggests that the latter might be effectively obtained directly by a Compressed Sensing (CS) type reconstruction [2]. We have tested this idea for the AFI mapping sequence [3]. It is shown that accurate reconstructions of simulated and measured in-vivo B1+ fields are possible using only 40% of the full dataset.

Theory: Consider a B1+ measurement sequence such as AFI in which two images I_1 and I_2 are acquired such that the flip angle θ is a function of the ratio $r = I_2/I_1$. In order to accelerate the B1+ mapping sequence we can randomly undersample the k-space data k_1 and k_2. This produces incoherent artifacts in the source images, I_1 and I_2. CS reconstruction of these images will not necessarily converge to the correct image ratio. However, we may formulate a reconstruction of r as the minimization of the cost function which finds the two source images consistent with the measured data whose ratio is sparse in the wavelet domain and smooth in image space. The cost function is given by Eqn. 1,

$$\min_{I_1, I_2} \; \| F_u I_1 - k_1 \|_2^2 + \| F_u I_2 - k_2 \|_2^2 + \lambda_W \| \Psi(r) \|_1 + \lambda_{TV} TV(r) \qquad (1)$$

where F_u is the undersampled Fourier Transform operator, Ψ(r) is the wavelet transform of r, TV(r) is the total variation of r and λ_W and λ_{TV} are weighting parameters.

The method developed is composed of two stages. First, as a pre-conditioning step, each undersampled source image is solved as an individual CS problem. Each of these two solutions are then refined using Eqn. 1 to produce the final ratio image. Both stages of the algorithm are solved using a nonlinear Conjugate Gradient algorithm with a backtracking line search [2].

Methods: A simulated dataset was created by multiplying a model polynomial flip angle distribution with a brain image to produce a pair of anatomical images which divided to produce the specified ratio. Their corresponding k-space data was then independently randomly undersampled in two dimensions by 60% and reconstructed. The second experiment reconstructed in-vivo B1+ map measurements with 60% 2D undersampling. The B1+ maps were acquired using slice-selective modified AFI [4] (FOV = 200^2mm, vox = 3x3x10mm, $TE/TR_1/TR_2$ = 4.6/30/150ms, flip angle = 80°, matrix size = 64^2) on a single transverse slice of the brain on a 3T Philips Achieva scanner. Reconstructions were performed on a standard desktop computer using MatLab. A Daubechies-4 wavelet transform was used as the sparsifying transform.

Results: Figure 1 shows the results of both the simulated and measured experiments. Images A and D show the B1+ maps using all k-space data. Images B and E show the B1+ map after the first stage of the reconstruction. Both images exhibit the approximate shape of the B1+ field but large errors still exist. The final stage of the proposed algorithm finds a set of images that are consistent with the data but whose ratio exhibits smoothness and sparsity in the wavelet domain. The reconstruction of the simulated B1+ map has an average pixel difference from the original of 2.3±0.1°.

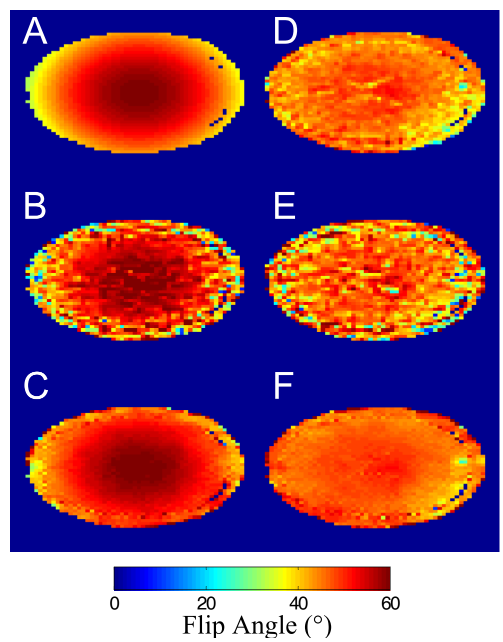

Figure 1 - Simulated and measured reconstructions. A) Simulated B1+ map, B) B1+ after first stage of reconstruction and C) Final Reconstruction. D) Measured B1+ map, E) B1+ after first stage of reconstruction and F) Final Reconstruction.

Discussion and Conclusion: We have proposed a method of accelerating flip angle mapping by exploiting the inherent smoothness of the B1+ field. The first stage of our algorithm provides images which are individually optimal but neglects their consistency when taking the image ratio. The second reconstruction stage then finds the pair of images which provide a smooth B1+ map which is sparse in the wavelet domain while remaining data consistent. Furthermore, this final step inherently acts to denoise the B1+ maps. The quality of the reconstruction reduces at the edges of the object for both simulated and reconstructed data. This is because the wavelet transform introduces artificial detail in the wavelet domain due to the sharp boundary between the object and air. In future work we will explore the use of different transform domains, such as Shape-Adaptive Discrete Wavelet Transforms [5] and Chebyshev polynomials, in which B1+ maps may be even sparser and therefore allow higher undersampling.

References: [1] Fernandez-Granada, C. & Sénégas, J. ISMRM 2009 #380 [2] Lustig, M. et. al. MRM 2007 58:1182 [3] Yarnykh, V. MRM (2006) 57:192 [4] Nehrke, K. (2008) MRM 61:84 [5] Li, S. & Li, W. IEEE Trans. Circuits Syst. Video Technol. (2000) 10:725