T1 Map Reconstruction from Under-sampled KSpace Data using a Similarity Constraint

Mohammad H Kayvanrad[1], A. Jonathan McLeod[1], John S. H. Baxter[1], Charles A McKenzie[1], and Terry M Peters[1]
[1]*Robarts Research Institute, The University of Western Ontario, London, Ontario, Canada*

Introduction: The long acquisition time in magnetic resonance imaging (MRI) often limits the number of pulse sequences that can be run on a patient in typical clinical applications; therefore, it is desirable to reduce the acquisition time without compromising the information obtained. This becomes particularly important in applications where a number of images should be acquired in order to reconstruct a map of quantity of interest, e.g. relaxation times T1 and T2. One approach to reducing acquisition time is to under-sample k-space and interpolate the missing samples by imposing some *a priori* sparsity constraints in a sparse domain (e.g., wavelet) [1]. Although this constraint still holds in problems involving multiple acquisitions, the similarity between images can lead to additional constraints. In this work we consider the problem of DESPOT1 [2] reconstruction of a T1 relaxation map from two under-sampled spoiled gradient recalled (SPGR) images obtained at two different flip angles, α_1, and α_2. Our hypothesis is that in addition to the (wavelet) sparsity constraint, the similarity of the images, measured in terms of mutual information, can be used as another reconstruction constraint to further improve the quality of reconstruction and/or increase k-space under-sampling.

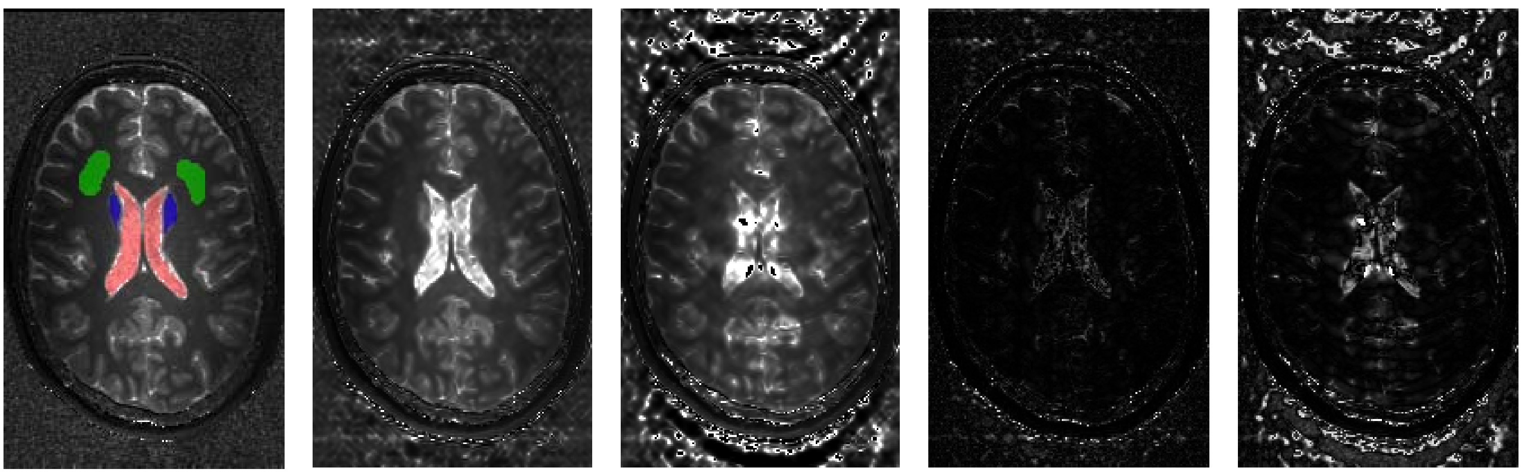
Methods: We consider the problem of reconstruction of a T1 map from two independently and randomly under-sampled SPGR k-space data, $F_{1,u}$ and $F_{2,u}$. To do so, we reconstruct the corresponding spatial images, f_1 and f_2, from the set of available under-sampled data, $F_{1,u}$ and $F_{2,u}$, by maximizing the their mutual information, as a similarity reconstruction constraint, in addition to the traditional sparsity constraint. The rationale is since f_1, and f_2 are consecutive acquisitions of the same object, we expect the structural information of the images to be the same (only with different intensity values). It is common to express the sparsity by an *l1* norm [3]. The reconstruction problem can, thus, be expressed as the following optimization problem, the solution to which we estimate by an iterative algorithm:

$$\min_{f_1^*, f_2^*} \left\| \Psi f_1^* \right\|_{l1} + \left\| \Psi f_2^* \right\|_{l1} - \lambda I(f_1^*, f_2^*) \quad s.t. \quad S_1 F_1^* = F_{1,u} \quad and \quad S_2 F_2^* = F_{2,u}$$

Here the minimizers are denoted by asterisk (*). $I(f_1^*,f_2^*)$ denotes the mutual information between f_1^* and f_2^*. ψ denotes the wavelet transform and $\|.\|_{l1}$ is the *l1* norm. $\lambda \geq 0$ is a weighting coefficient. S_1 and S_2 are the k-space (under)sampling operations (that is, $F_{1,u}=S_1F_1$ and $F_{2,u}=S_2F_2$, where F_1 and F_2 are the Fourier transforms of f_1 and f_2, respectively).

Two whole-brain 3D SPGR images of a volunteer were acquired at 3T with flip angles 4° and 18°. Corresponding slices were selected from each volume, from which the corresponding 2D T1 map was computed by the T1 mapping technique DESPOT1, as the gold standard. Each slice was independently and randomly under-sampled. Each two corresponding slices (at flip angles 4° and 18°) were then (jointly) reconstructed with the sparsity and mutual information constraints, and the corresponding T1 map was computed by DESPOT1. Human data used in this work were acquired using a protocol approved by the institutional Office of Research Ethics.

Results: Figure 1 compares the T1 maps computed by simultaneously maximizing sparsity and mutual information with the traditional reconstruction by sparsity only as well as with the gold standard. Table 1 compares the statistics of the computed T1 values over 3 samples, i.e., regions of interests, defined on CSF, white matter, and gray matter. The mutual information constraint results in noticeable improvement in the quality of reconstruction.



(a) Gold standard + ROIs (b) MI and Sparsity (c) Sparsity only (d) Difference (b) & (a) (e) Difference (c) & (a)

Figure 1- Reconstruction of T1 map by DESPOT1 from two SPGR images acquired at flip angles 4° and 18°; (a) fully-sampled (256×156) k-space data (Gold standard), and the ROIs used in table 1: red corresponds to CSF, blue to gray matter, and green to white matter; (b) under-sampled k-space, reconstruction by maximizing wavelet sparsity of each image and their mutual information; (c) under-sampled k-space, reconstruction by maximizing wavelet sparsity of each image only.; (d) and (e) difference images for comparison of the quality of reconstruction with the gold standard. Each image (corresponding to flip angles 4° or 18°) is under-sampled by 3, i.e., the acquisition time will be reduced by a factor 3.

Discussion: DESPOT1 T1 map acquisition can be accelerated by under-sampling k-space and using the similarity between the consecutive acquisitions, measured in terms of mutual information, as an additional reconstruction constraint beside (wavelet) sparsity, while maintaining an acceptable quality of reconstruction. This accelerated acquisition is of particular importance in clinical applications. For instance, an acceleration ratio of 3, which is the case in figure 1, can result in a reduction in the acquisition time from 20 minutes to 7 minutes in a typical full 3D isotopically resolved T1 and T2 map acquisition [4]. This could be the difference between acquiring additional pulse sequences on the patient or not. Finally, while we express our results for DESPOT1 with acquisition of two SPGR images at two different flip angles, this does not affect the generality of the problem described here, and the method can be applied for reconstruction of any consecutive acquisitions with any T1/T2 mapping techniques or other approaches that require the acquisition of a series of sequential images.

		(a)	(b)	(c)
CSF	Mean	4.1e+003	4.0e+003	3.3e+003
	Std	7.7 e+002	7.6 e+002	1.3e+003
WM	Mean	7.7 e+002	7.6 e+002	7.9e+002
	Std	9.0 e+001	1.0 e+002	1.2 e+002
GM	Mean	1.5e+003	1.6e+003	1.7e+003
	Std	1.6 e+002	2.2 e+002	7.8 e+002

Table 1- Statistical comparison of the T1 values (ms) corresponding to figures 1(a), (b), and (c) over the 3 ROIs defined on CSF, WM, and GM, as shown in figure 1(a).

References: [1] Lustig et al. Magn. Reson. Med. 2007 Dec;58(6):1182–95. [2] Deoni et al. Magn. Reson. Med. 2003 Mar;49(3):515–26. [3] Candes et al. Sig. Proc. Mag., IEEE. 2008;25(2):21–30. [4] Deoni et al. J Magn Reson Imaging. 2007 Oct;26(4):1106–11.