Multi-scale graph cut algorithm for water/fat separation

Johan Berglund[1]
[1]*Karolinska Institutet, Stockholm, Sweden*

Purpose: Several water/fat separation methods use *graph cuts* to resolve the B_0 field map prior to water and fat component estimation in each voxel separately[1-3]. These algorithms have demonstrated robustness to severe field inhomogeneity, but the tolerance to noise has not been well examined. The purpose of this work is to develop a method that performs well even for noisy input data.

Methods: The algorithm by Berglund and Kullberg[2] (referred to as the *single-scale algorithm*) is computationally efficient, since it performs a single binary graph cut. The field map values resolved by the graph cut are guaranteed to be part of a globally optimal solution in terms of the objective energy function. Less desirable, not all voxel may receive a solution and must be resolved using some other heuristic[2,4]. This is mainly an issue for noisy voxels. We propose a *multi-scale algorithm* to handle this problem. Multiple energy functions are defined at progressively coarser resolution levels, by adding the energies from neighbor voxel pairs along each spatial dimension, and minimized at each level using the single-scale algorithm. Unresolved voxels are assigned the field map value from its super-voxel at the nearest coarser level. The coarsest level is represented by a single voxel, so the global minimum can be found by exhaustive search over a single variable. Thus, each voxel is assigned a field map value which belongs to a globally optimal solution at some resolution level. Both algorithms were evaluated by reconstructing 13 datasets from the 2012 ISMRM challenge on water/fat separation. In addition, all datasets were retrospectively degraded, by adding white complex Gaussian noise, in order to synthesize a range of SNR levels.

Results: The reconstruction accuracy was defined as the fraction of voxels within a foreground mask where the calculated field map value deviated no more than 1 ppm from the field map obtained at full SNR (which had no associated water/fat swaps for any of the datasets). The accuracy of the two methods for varying input SNR is shown in Fig. 1. The multi-scale algorithm was equally or more accurate than the single-scale algorithm for all cases at all SNR levels. The benefit of multi-scale processing was small in some cases, while substantial in others, such as the case shown in Fig. 2.

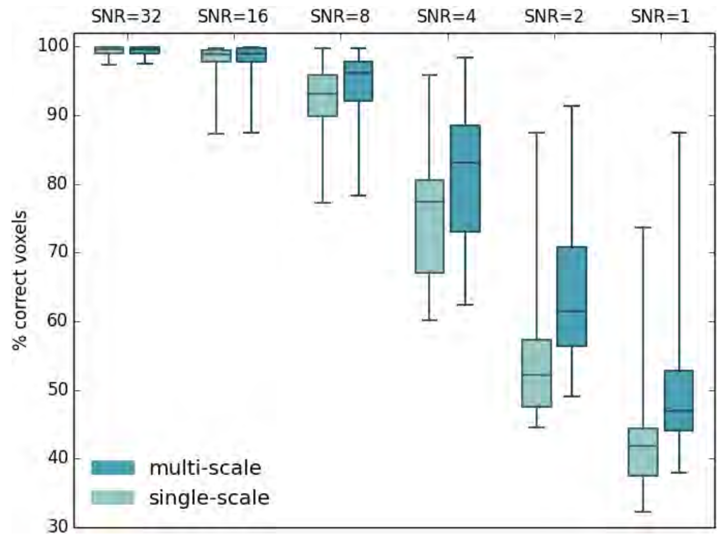

Fig. 1. *Method accuracy as function of input SNR. The boxes and whiskers show the spread over the 13 datasets. The multi-scale algorithm performs better than the single-scale algorithm for low input SNR.*

Discussion: The multi-scale processing solves the problem of unresolved voxels for the single-scale algorithm, and improves the water/fat separation with only a minor increase of the computational burden. Additional graph cuts must be performed at the coarser resolution levels, but the total number of nodes at these levels are only 1/3 of the nodes at full resolution (1/7 for 3D). For high-resolution data, it might be sufficient to determine the field map at a coarser scale. Such a modification of the multi-scale algorithm is straightforward. In conclusion, the multi-scale algorithm is more robust to noise in the input data than the single-scale algorithm.

References: 1. Hernando D, Kellman P, Haldar JP, Liang Z-P. Robust water/fat separation in the presence of large field inhomogeneities using a graph cut algorithm. Magn Reson Med 2010;63(1):79–90. **2.** Berglund J, Kullberg J. Three-dimensional water/fat separation and *T*2* estimation based on whole-image optimization–Application in breathhold liver imaging at 1.5 T. Magn Reson Med 2012;67(6):1684–1693. **3.** Cui C, Wu X, Newell JD, Jacob M. Fat water decomposition using globally optimal surface estimation (GOOSE) algorithm. Magn Reson Med (early view); DOI: 10.1002/mrm.25193. **4.** Kolmogorov V, Rother C. Minimizing nonsubmodular functions with graph cuts–a review. IEEE Trans Pattern Anal 2007;29(7):1274–1279.

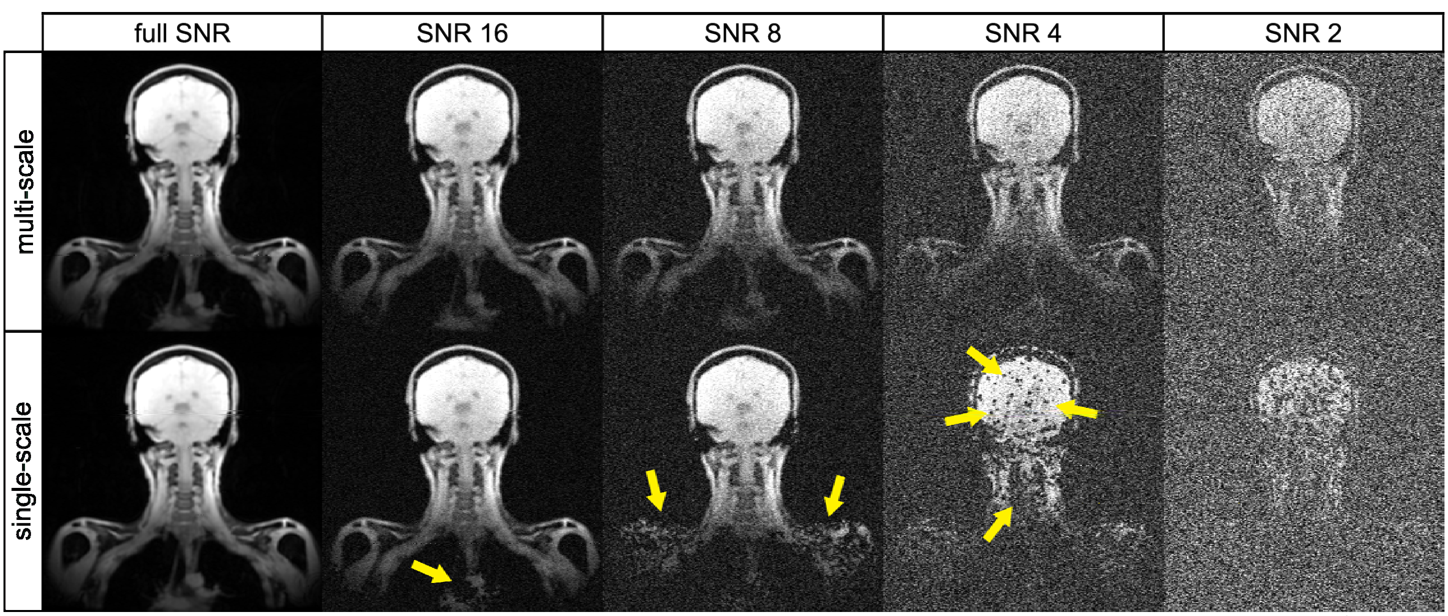

Fig. 2. *Water image reconstructed using both the multi-scale and single-scale algorithms at varying SNR levels. The single-scale algorithm results in water/fat swaps (indicated by arrows) at low SNR, while the multi-scale algorithm degrades gracefully as SNR decreases.*