Optimization of Fat-Water Separation Algorithm Selection and Options Using Image-based Metrics with Validation by ISMRM Fat-Water Challenge Datasets

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Purpose: The objective of this research is to develop and describe a robust fat-water separation algorithm for multi-echo MRI that is applicable to datasets spanning a wide range of anatomy, magnetic field strengths and collected echo times. The algorithm is validated in the context of the 2012 ISMRM Fat Water Challenge [1]. Though several months remain before the challenge enters the final stage, we believe our currently 3rd place team, Fatty Riot, will likely be one of the five top teams to proceed to the second (and last) phase of the contest in which teams are completely blind to the test datasets. In the blinded phase of the competition, it will not be possible to manually tweak algorithms to produce better results. We believe that the ultimate winning entry will contain logic to predict the best (or nearly best) option among multiple results. We outline below our current embodiment of such an algorithm with the disclaimer that our algorithm will evolve over the coming months of the competition. In the spirit of healthy competition, we do not specifically name the image-based metrics we are using to compare results from multiple fat-water separation algorithms. However, we will fully describe all components of our algorithm at the 21st Annual Meeting of the ISMRM in Salt Lake City, Utah regardless of our final standing in the 2012 ISMRM Fat Water Challenge.

Methods: The team name Fatty Riot was registered with member names matching the coauthors of this abstract. The 10 test cases of the challenge were downloaded and processed with a combination of code run in MATLAB R2010a (Natick, MA) and C++. A combination of algorithms available in the ISMRM Fat-Water Toolbox [2] were selected for evaluation including a graph cut method [3-4] with fieldmap regularization [5], multi-seeded region growing approach [6], and a mixed magnitude/complex signal model fitting to address potential eddy current phase errors [7]. We also applied an algorithm currently not available in the ISMRM toolbox that uses a whole-image energy cost function minimization approach [8]. Because algorithms vary in compatibility with respect to the number of echoes and echo spacing, the first step of the Fatty Riot algorithm is to determine compatibility with each candidate algorithm. Each test dataset in the contest was guaranteed to have at least three evenly spaced echoes such that even the most restricted of the tested algorithms [6] could be applied once a compatible set of echoes was selected. Some of the candidate algorithms are compatible with 3D data, and processing in 3D instead of as a series of multiple 2D slices often produces better results if the dataset has no serious phase discontinuities in the through-plane (slice) direction. Among the test cases, at least one case (Case 9: 3T axial brain) was observed to have a slice inconsistency that confounds 3D algorithms. Therefore, one of the fast algorithms [6] was applied in both 2D and 3D to determine if 3D processing was advisable. An image-based metric, M_{2Dvs3D}, was developed to evaluate the quality of the 2D versus 3D result. Following the initial 2D/3D test, the other candidate algorithms were applied. Some candidate algorithms were always run in 2D mode [3-5]. The mixed signal model algorithm [7] was run as a refinement step to the output of the other candidate algorithms on a voxel-by-voxel basis with as many voxels analyzed as possible in the 30 minutes maximum processing time allowed for a case in the blinded stage of the contest. All candidate fat-water separation results were evaluated with another image-based quality metric, $M_{Quality}$, to select the result to return as the final result.

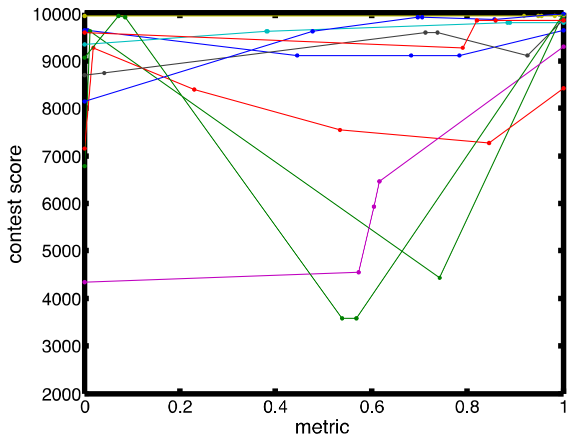

Figure 1. Plot of image metrics versus scores for all ten contest cases.

Case	1	2	3	4	5	6	7	8	9	10
Spearman's rho	0.116	0.471	0.200	0.971	0.986	0.754	0.812	0.771	0.086	0.618

Table 1: Spearman's rank correlation coefficient (rho) for the metric used for each case.

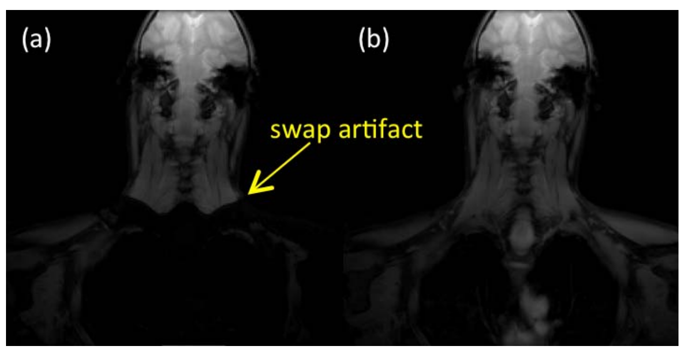

Figure 2. Case 2 water image results from the graph cut algorithm [3-5] with normalized image-based quality metric $M_{Quality}$=0.000 (worst result) and the whole-image optimization algorithm [8] with $M_{Quality}$=1.000 (best result).

Results: Figure 1 plots scores and normalized (per case) image-based quality metric values for the 10 contest datasets and candidate algorithms. Higher values of the metric generally correspond to higher scores. Table 1 confirms this with Spearman's rank correlation coefficient values between contest score vs. $M_{Quality}$. However, the Spearman rank correlation is not high for all cases, and we will continue to evaluate other metrics. Figure 2 shows example water images from the candidate fat-water image separation results obtained from the graph cut [3-5] and whole-image optimization [8] methods for a particularly challenging case (Case 2: 3T coronal head/neck). The whole-image optimization approach produces the better result and has the higher $M_{Quality}$ metric value so that it will be selected to return.

Discussion: Our image-based metric-driven algorithm is just one of many vying for the top award in the 2012 ISMRM Fat-Water Challenge. No matter the outcome of the contest, we expect to learn about many other excellent solutions developed by other talented teams to overcome the obstacles presented by the ISMRM Fat-Water Challenge, and we look forward to sharing all the details of our final algorithm embodiment.

References: [1] Samsonov A and Tsao. ISMRM Challenge 2012. http://www.ismrm.org/challenge [2] Hernando D, et al. ISMRM Fat Water Toolbox v1.0. http://ismrm.org/workshops/FatWater12/data.htm 2012 [3] Hernando D, et al. *MRM* **63**(1):79-90; 2010. [4] Gleich D. MATLAB BGL v4.0, http://www.cs.purdue.edu/homes/dgleich/packages/matlab_bgl 2008. [5] Huh W, et al. 16th ISMRM, Toronto, Canada: 1382; 2008. [6] Berglund J, et al. *MRM* **63**(6):1659-68; 2010. [7] Hernando D, et al. *MRM* **67**(3): 638-44; 2012. [8] Berglund J, et al. *MRM* **67**(6):1684-93; 2012.