Robust Field Map Estimation in a Dixon Water-Fat Separation Algorithm with Short Echo Time Increments

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Introduction: Many important clinical MRI procedures require robust fat suppression or water-fat separation. Among various separation techniques, the 3-point Dixon method is particularly advantageous in terms of its relative tolerance to field inhomogeneity [1]. If the field inhomogeneity map is known *a priori*, perfect separation of fat and water can be obtained. In the 3-point Dixon method, the measured data are used to obtain a "field map" along with separated water and fat images.

The 3-point Dixon method uses echo times (in GRE) or echo time shifts (in SE) such that the phase difference of water and fat is at either 0 or a multiple of π at the echo times. An extension has been proposed recently [2] that can work with arbitrary fat-water phase shifts. This can be used to shorten echo time increments, which can help reduce image artifacts. For example, short TRs are necessary with SSFP to prevent banding artifacts and short echo spacing with FSE is needed to reduce image blurring. An iterative method is used to estimate the field map from the three echo images. The source images are then corrected with the estimated field map, and water and fat images are calculated from a linear least-squares fit. The field map estimation is a critical step in this method. As will be shown, in certain circumstances the field map estimated at some pixels may be incorrect, leading to imperfect separation. The aims of this work are to understand this behavior in field map estimation and to propose a more robust field map estimation algorithm.

Theory: Following [2], we model the signals (source images) of each pixel at echo time TEn (n = 1, 2, 3) as: $S(TE_n) = (W + F \cdot e^{j2\pi\Delta f TE_n})e^{j2\pi\psi TE_n}$, where W and F are water and fat components in the pixel. Δf is the off-resonance frequency of fat relative to water, and at 1.5T, is approximately 220Hz. ψ is the field map term at the pixel, which is unknown and must be estimated.

It can be shown that if the pixel is purely water or fat, there is a natural ambiguity and there are two solutions. If the true solution is (W_t F_t ψ_t), the other solution is described as (F_t W_t $\psi_a = \psi_t - \Delta f$) for a water pixel, or (F_t W_t $\psi_a = \psi_t + \Delta f$) for a fat pixel. Here, we have used ψ_a to denote the undesired solution of the field map, which we will call the "aliased" field map. If the initial value of the iterative field map estimation at a pixel is closer to the aliased value ψ_a than to the true value ψ_t, the algorithm may converge to the aliased solution. In that case, the estimated values for water and fat will be swapped for this pixel. While this problem is most severe when a pixel contains only fat or water, in general, the aliased field map value is in the form of either an exact solution or a local minimum. Therefore, one way to improve the accuracy of the field map estimation is to start the iterative calculation of the field map with a carefully chosen initial value.

Method: The original iterative field map estimation is operated independently over all the pixels in the image with initial guess of 0 Hz. In our improved method, we start the field map estimation with a more reasonable initial value at each pixel and use the *a priori* assumption that the field map should not vary rapidly in neighboring pixels. These goals can be achieved by using a region-growing algorithm guided by a low-resolution Dixon reconstruction. The idea of low-resolution reconstruction has been used previously in similar situations [3]. The algorithm steps are:

1). The source images are smoothed and down-sampled to a low-resolution (eg. 32x32) set of source images.
2). The previous algorithm [2] is performed on the low-resolution source images to yield a low-resolution field map.
3). A signal threshold binary mask is generated from the low resolution source images and applied to the low-resolution field map to suppress the noisy estimates in the background region.
4). A pixel with the median value is identified in the signal-thresholded low-resolution field map. This pixel corresponds to a small group of pixels in original resolution images. The pixel (in the original high resolution images) with the highest signal among this small group is selected. This pixel is called the starting pixel.
5). The field map ψ at this starting pixel is estimated using the result of the low resolution fit as the initial value for the iteration.
6). The field map term, ψ, of a pixel next to the starting pixel is estimated using the field offset value of the starting pixel as the initial value.
7). This procedure is repeated, growing the region by using the result of the previous pixel as the initial value for a neighboring pixel until all the pixels are estimated.

The pixel trajectory for region growing is spiral-like, initiated from the starting pixel. It is crucial to start the region growing at a pixel with a correct value. As described above, we start at the pixel with the median field map value from the low-resolution reconstruction. This is based on the observation that pixels that converge to the aliased field map have very high or very low fitted field map values. The proposed new method has been tested on 18 data sets from healthy volunteers, spanning a range of clinical applications such as knee, ankle, cardiac, cervical, and shoulder imaging. GE 1.5T Signa Twin Speed and GE 3T scanners were used.

Results: Figure 1 shows the reconstruction of a dataset using the original field map estimation method (b-d) and the new method (f-h). The data is from a FSE Dixon acquisition at 1.5T with echo times of [-1.5ms, 0, 1.5ms]. In the field map image with the original method (d), pixels in the regions indicated by arrows converged to the aliased field map values, which were approximately the true field map plus 220Hz in fat regions. This is reflected also in the water and fat images (b, c). The product fat saturation image (NSA=4) showed incomplete fat-saturation at the same location (e) due to field inhomogeneity sensitivity. By comparison, the new method successfully resolves the ambiguity problem and generates correct water and fat images. The new method has worked similarly well in 17 other data sets.

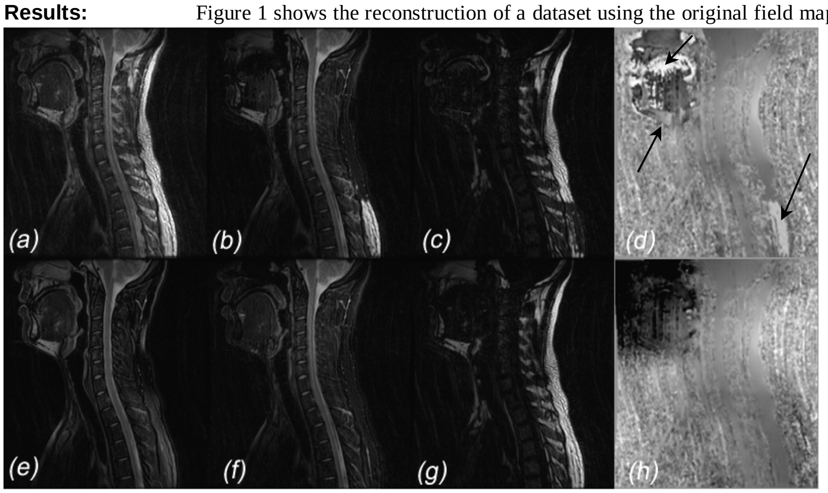

Figure 1: A sagittal slice of the cervical spine: (a) one of the source images; (b-d) water (b), fat (c) and field map (d) using original method; arrows in (d) shows regions that converged to the aliased field map; (e) fatsat image with NSA=4 has difficulties in the same areas; (f-h) separated water (f), fat (g) and estimated field map (h) using the new method.

Conclusion: We have shown that there is an intrinsic ambiguity in the Dixon technique with short echo time increments, which can be resolved by an improved field map estimation method proposed here. This robust method increases the method's immunity to field inhomogeneity.

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Ref:

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