A Multi-Mask Multi-Seed Free Growing Field Map Estimation Algorithm for Iterative Multi-Point Water-Fat Decomposition

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Introduction: In MRI, fat/water separation in the presence of B_0 field inhomogeneity is an important research area. An iterative method called IDEAL, based on a three-point Dixon technique, is one of the methods recently proposed to solve this problem [1]. In IDEAL the field inhomogeneity or the field map (**Ψ**) is incorporated into the 2 chemical species signal model. A key step in IDEAL is to have an initial estimate of **Ψ**, which is close to the true value, to ensure that the algorithm will converge to the correct solution. A region growing (RG) algorithm has been combined with IDEAL to provide the initial estimate of **Ψ** [2]. Our experiments have shown that the RG method fails in many instances if there are large regions in the image with very low signal intensity. This is the case for black-blood images of the heart the area occupied by the lungs creates large regions of low signal intensity. In this work, we introduce a new method called Multi-mask Multi-seed Free Growing (MMS-FG) as an alternative to the RG algorithm.

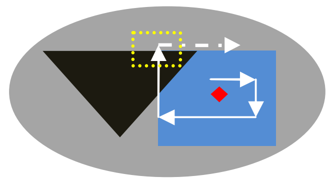

Figure 1.

Theory: Figure 1 shows a schematic representation of an object with areas of high signal intensity (*gray region*) and a large region of low signal intensity (*black triangle*). In the RG algorithm a small starting region (seed) is selected (*red diamond*) in a location where it is assumed that **Ψ** can be accurately estimated [2]. The values of **Ψ** obtained for the seed region are then used as an initial condition for the next pixel which is chosen using a spiral trajectory emanating from the starting region. For each pixel in the spiral trajectory, IDEAL is run with an initial **Ψ** estimate obtained using a linear extrapolation of the values of **Ψ** from pixels already visited by the spiral (*blue region* in Fig. 1). The linear extrapolation is performed using only pixels that are within a box in the neighborhood of the pixel being estimated. This neighborhood must contain a sufficient number of pixels for which **Ψ** has been accurately estimated to allow for a good initial estimate of **Ψ** at the current location. In this manner, the region with estimated **Ψ** keeps growing until the entire FOV is covered.

When a large region with low signal intensity exists in the image, the RG method may fail because for certain pixels in the image, the box that is used in the extrapolation step will consist of mostly noise pixels which don't provide enough information for the estimation of **Ψ**. This is illustrated in Fig. 1 by the *dotted box* where all the pixels inside the box are either noisy pixels or un-estimated pixels (*gray pixels*). Thus the estimation of **Ψ** for the pixel in the center of box may be incorrect and the error will propagate as the spiral trajectory continues. This problem may be solved by choosing a larger box in the hopes that more pixels with signal will be included. However, if the box is too large there will be problems in tracking fast changes in **Ψ** such as those caused by strong field inhomogeneity.

In the proposed MMS-FG method, a small box size is used to track quick changes in the field map. To avoid extrapolating in areas without signal, the method does not grow in the spiral trajectory, but instead, the trajectory is adapted to the signal intensity variation of the image. The steps on the MMS-FG method are:

1. Construct a series of **N** masks of decreasing signal threshold. An automatic threshold selection method based on the Rician distribution of the noise in the image domain is used for mask construction.
2. Of the pixels contained within the 1st mask, pick several seeds (**S** seeds) using a modified version of the seed picking algorithm described in [2].
3. Compute **Ψ** for all the seeds independently.
4. Find all the un-estimated pixels that have more than **L** estimated neighboring pixels. A neighborhood is defined by a **b**x**b** box centered at each un-estimated pixel.
5. For each pixel found in 4, use a 2D linear approximation on a **KxK** box centered at this pixel, followed by IDEAL using the approximation as initial value to estimate **Ψ**.
6. Repeat 4-5 until the region within the mask cannot grow.
7. Repeat 4-6 for the next mask, until all **N** masks are used.
8. For multi-coil acqusitions, steps 3-7 are performed for each of the coils. The overall **Ψ** is calculated by the signal intensity weighted average of the **Ψ** of all the coils.
9. Compute the fat/water map using the **Ψ** map calculated above.

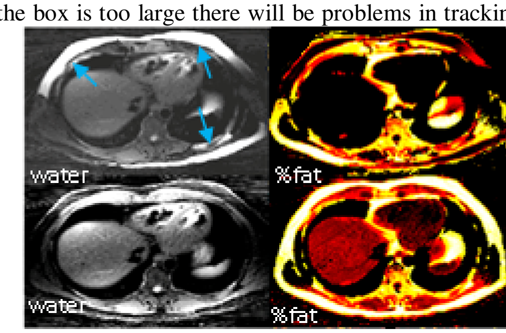

Figure 2. Water images and %fat signal maps obtained with IDEAL and (bottom) the RG algorithm and (top) the MMS-FG algorithm.

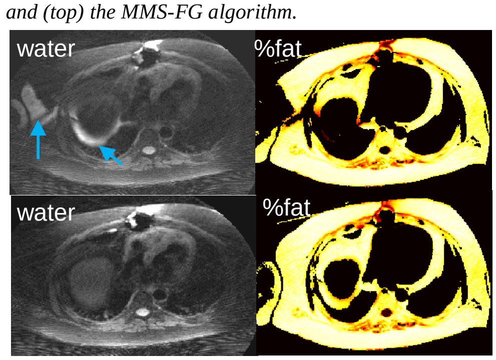

Figure 3. Water images and %fat signal maps obtained with IDEAL and (bottom) the RG algorithm and (top) the MMS-FG alaorithm.

Method: A double-inversion cardiac-gated radial gradient and spin echo (GRASE) sequence was used with 4 gradient echoes collected per spin-echo period. The images obtained from these 4 gradient echo data sets have different fat-water phase shifts and were used for fat-water separation. Data were acquired at 1.5T with phase shifts between water and fat: ($-3\pi/2$, $-\pi/2$, $\pi/2$, $3\pi/2$). Other parameters were: BW=±64 kHz, ETL=10, matrix size=256×192, TR=1RR, NEX=1. The MMS-FG parameters were N=3, S=7, L=15, b=7, B=15.

Results: Figures 2 and 3 show the water images and %lipid signal maps (generated from the water and fat images) obtained using the RG method and the MMS-FG method for two cardiac data sets. In both cases there are large regions within the anatomy that have low signal intensity. The MMS-FG method yields better fat-water separation results than the RG method. As shown in Fig. 2, in the images processed with the RG algorithm there are regions where fat and water pixels are misregistered (*arrows*). The images in Fig. 3 are from a patient with surgical wires in the sternum which cause significant local susceptibility changes. Since a small box size (15x15 pixels) is used in the extrapolation step, we can track the fast changes in the field map around the sternum. However, in the images processed with the RG algorithm there are areas of misregistration (*arrows*). In the image processed with MMS-FG there is only a slight distortion around the sternum but the rest of the pixels are registered correctly.

Conclusion: A new algorithm has been developed to estimate the field map associated with fat-water separation. The algorithm is more robust than a region growing algorithm previously described. This provides an improved methodology for fat-water separation in cardiac imaging.

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