Three dimensional phase sensitive reconstruction for water/fat separation in MR imaging using inverse gradient

J. Rydell[1,2], A. Johansson[3], O. D. Leinhard[2,3], H. Knutsson[1,2], G. Farnebäck[1], P. Lundberg[2,3], and M. Borga[1,2]

[1]Department of Biomedical Engineering, Linköping University, Linköping, Sweden, [2]Center for Medical Image Science and Visualization (CMIV), Linköping, Sweden, [3]Faculty of Health Sciences/Radiation Physics, Linköping University, Linköping, Sweden

INTRODUCTION:

In- and out-of-phase imaging is a useful tool in quantitative imaging of fat. Several approaches have been implemented to improve the original two point Dixon method [1], often by introducing an extra point to increase the reliability of the reconstruction hence increasing scan time. Recent papers have shown promising results with two point protocols [2,3] although in our experience difficulties exist in areas with fast phase fluctuations and high uncertainty. Especially in lean subjects errors can be introduced due to lack of reliable phase information. The results can significantly be improved by considering phase sensitive reconstruction in three dimensions taking advantage of information in neighboring slices. A three dimensional phase sensitive reconstruction method has been implemented based on the inverse gradient approach [3,4]. The results have been compared with the original two dimensional inverse gradient method as well as with an established two dimensional region growing method proposed by Ma et.al. [2]. In contrast to correction based on region growing, the inverse gradient approach is straight forward to implement in three dimensions. The three dimensional method shows better processing results in areas of high noise and fast phase change.

METHODS:

The in- and out-of-phase images obtained from a two point Dixon protocol can be described as: $I=(w+f)\cdot e^{i\Phi 1}$, $O=(w-f)\cdot e^{i\Phi 2}$ where $\Phi 1$ and $\Phi 2$ are the accumulated phase fields at each echo time due to experimental factors such as *B0* inhomogeneity. The phase of the in-phase image can be easily removed by taking the magnitude of *I* as both fat and water signals are positive. Removing the phase term in the out-of-phase image is not as easy since *O* can be positive or negative depending on the dominance of the two constituents, therefore phase sensitive reconstruction is needed. Before processing the out-of-phase image static phase errors can be removed by subtracting the phase field from the in-phase image, $\hat{O}=(w-f)\cdot e^{i(\Phi 1-\Phi 2)}$, leaving the accumulated phase between the two echoes with water/fat dominance sign. $\hat{O}$ is the input source to the unwrapping process. The two implemented approaches are described below. For more thoroughly descriptions see [2] and [3].

Inverse gradient correction scheme:

1. Calculate a synthetic in-phase image $\hat{O}^* = \|\hat{O}\|\cdot e^{i2arg(\hat{O})}$ from the out-of-phase image by doubling the phase. This removes the water/fat dominance sign which means that water and fat signals are in phase and the phase error due to magnetic field inhomogeneities are twice as large as in $\hat{O}$.
2. Find the gradient fields of $\hat{O}^*$ describing the phase changes in x-, y- and z-directions respectively.
3. Multiply the gradient fields with a factor of 0.5 as they vary twice as fast in $\hat{O}$.
4. Use normalized convolution [5] for interpolation in uncertain regions where the phase values are expected to be noisy.
5. Compute an estimated phase field by integrating the gradient fields with the use of a Poisson solver described in [4].
6. Apply the estimated field on the out-of-phase volume to obtain a corrected volume.

Repeat all steps and iterate a solution until a specific criterion is met or a defined number of iterations are reached.

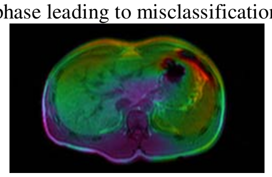
Region growing correction:

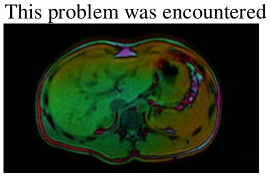
The main theory behind the region growing correction scheme is to unwrap pixels with low phase variations before pixels with high phase variations to get a more reliable processing. Multiple pixel stacks are used in combination with phase gradient maps *Gx* and *Gy*, representing the phase differences in x and y directions. The region growing is jump started by placing an arbitrary initial seed on the pixel stack. It is then traversed by continuously selecting the seed from the lowest non empty pixel stack. Neighbouring pixels are added according to their *Gx* and *Gy* value. The signal direction of the seed pixel is determined based on earlier determined pixels. When all pixel stacks are empty an averaging smoothing function is applied to remove isolated erroneously pixels followed by a smoothing filter. The phase field from the resulting image is used for correcting the out of phase image.

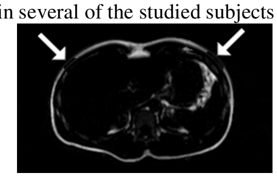
Data acquisition: 50 volumes from 20 different patients were collected. Single breath hold (28 s) multi-slice MR-images were acquired out of and in phase (TE = 2.3 and 4.6 ms) using a 1.5 T MR-scanner (Philips Medical systems, Best, the Netherlands). Slice thickness was 5 mm and the field of view was 290x200x410 mm (ap, fh, rl). TR was 286 ms and the flip angle was 80 degrees. The signal intensities were rescaled to the sensitivity of the quadrature body coil using constant level appearance (CLEAR) reconstruction.

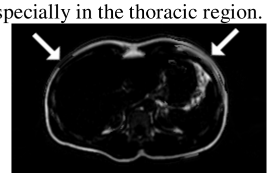
RESULTS:

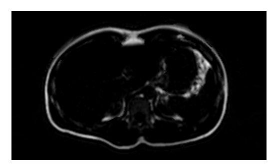
The images represent cases that the 3D algorithm successfully solved while the 2D algorithms failed. The complex in- and out-of-phase images are shown where intensity corresponds to magnitude and color represents phase. In the first row subcutaneous fat has been misclassified due to a too small phase difference between subcutaneous fat and underlying tissue. In the second row a fast phase leap has introduced an erroneously classification of the stomach. Arrows indicate the misclassified areas. As can be seen in the in- and out-of-phase images the phase variations are small over the images but still contain troublesome areas with uncertain phase leading to misclassifications. This problem was encountered in several of the studied subjects especially in the thoracic region.

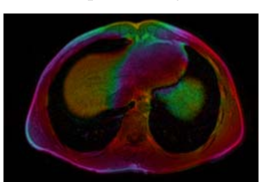

In-phase image.

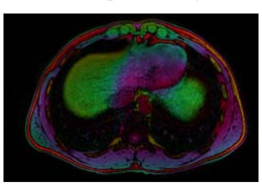

Out-of-phase image.

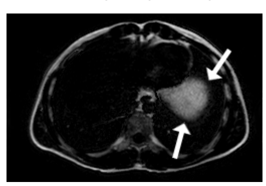

Fat, region growing.

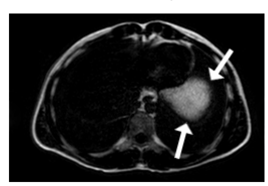

Fat, 2D inverse gradient.

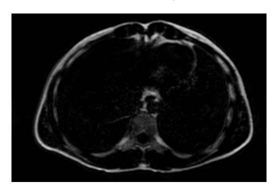

Fat, 3D inverse gradient.


In-phase image.


Out-of-phase image.


Fat, region growing.


Fat, 2D inverse gradient.


Fat, 3D inverse gradient.

CONCLUSION:

Three-dimensional phase estimation and correction is important since the phase in a two dimensional slice may contain unreliable phase regions making it difficult to estimate in 2D while being trivial in 3D.

REFERENCES: **1**.Dixon.Radiology,1984.**2**.Ma,J. Magnetic Resonance in Medicine,2004.**3**.Rydell,J. MICCAI'07.**4**.Farnebäck,G.MMBIA'07.**5.**Knutsson,H.SCIA'93.