An Efficient and Effective Algorithm for Two-Point Fat-Water Separation

M. A. Schmidt[1], K. M. Fraser[1]
[1]Department of Medical Physics, St George's Hospital, London, United Kingdom

Introduction

Phase-based methods for separation of fat and water signals are affected by magnetic field inhomogeneity and require field mapping prior to producing separate fat and water images [1]. Phase unwrapping is often required and this process is anything but trivial in the presence of noise or artifacts [2]. An alternative region-growing phase correction algorithm was recently proposed by Ma [3], with the advantage of using only two images (fat and water signals in-phase and out-of-phase). It works by detecting large phase shifts associated with the boundary between water-dominant and fat-dominant regions in out-of-phase images. This work investigates the performance of the phase correction method in the presence of noise and magnetic field inhomogeneity, with particular attention to the air-tissue interfaces in the head. In addition we propose an improved 2-pt phase-correction algorithm that is faster, less sensitive to noise and therefore more robust.

Methods

Experimental: This work was undertaken at 1.5T (GE Signa/echo-speed gradients, Milwaukee, USA). In-phase and out-of-phase gradient-echo images were acquired with full echoes only (TE from 6.6 ms to 13.4 ms, ±32 kHz receiver bandwidth). These fairly long TEs ensured that the fat-water separation algorithms were evaluated in the absence of phase drifts associated with asymmetric echoes or eddy-currents. Phase correction methods were employed on the first two images, and the 3-pt Dixon was employed as a gold standard when required. Other imaging parameters were adapted to each individual experiment. Two 2-pt Dixon algorithms were implemented in IDL: **(A)** the original phase correction algorithm [3] and **(B)** the modified region growing algorithm described below. In order to evaluate the algorithms a 7 cm diameter sphere containing vegetable oil and a $CuSO_4$ solution was imaged at 10 degrees to the horizontal oil-water interface. Magnetic field inhomogeneity was introduced by placing a strongly paramagnetic solution of dimeglumine gadopentetate in the vicinity of the test object (concentrated Magnevist, 0.5 mol/l, Schering, Berlin, Germany). Volunteers had their head scanned with the approval of the Ethics Committee.

A. The Phase Correction Algorithm: Starting from an arbitrary seed point, the region growing process is guided by the phase-gradient based quality maps [3].which are expected to direct the process towards regions where the magnetic field inhomogeneity is lowest, irrespective of the phase shifts associated with water-fat interfaces. Every pixel added to the region has its phase compared to the average phase of the neighbourhood pixels already within the region. If the phase difference is greater than $\pi/2$ it is assumed that the boundary between a water-dominant and a fat-dominant region was crossed. In that case the phase of the new pixel is corrected by adding/subtracting π, producing a corrected phase map (CPM). A record of the pixels where the phase swap was necessary is kept (SWP). The process ends when all pixels are included in the region, and it ceases growing. The CPM is subtracted from the phase images, with the purpose of removing phase shifts associated with magnetic field inhomogeneity. Thus the SWP matrix contains the information on the sign of the fat-water out-of-phase image.

B. The Modified Algorithm: Two fundamental modifications are proposed to the original phase correction algorithm. **(i)** The region growing process begins with images of lower resolution. This not only increases the SNR and processing speed, but also allows the region growing process to progress more easily from fat-dominant to water-dominant regions in areas of good field homogeneity. The resulting low resolution CPM and SWP images are adopted as correct only for the pixels where the phase of the low resolution image is a good approximation for the phase of the original image. Those pixels which were not adopted as correct are taken to the next stage, where the process is restarted with images of higher resolution until it reaches the resolution of the original images. **(ii)** The final CPM is manipulated with low-pass filters prior to being used to remove the effects of magnetic field inhomogeneity from the original images. This final step removes the assumption that a sharp phase change (approximately π) occurs at the boundary between fat and water dominant regions, and allows for the occurrence of smoother phase variations which are observed in practice.

Results

The original phase correction algorithm fails to detect a boundary between water and oil in the spherical water-oil test object due to the low phase gradient at the interface. This issue is unrelated to SNR and the quality map actually leads the region growing process to the areas where the phase gradient is lowest. The low phase gradient at water-fat interfaces is also apparent in clinical images, as shown in the quality maps of Figure 1, for a healthy volunteer. The modified 2 pt phase correction algorithm succeeds in separating fat and water in the spherical test object, even for a lower SNR (Figure 2). The final step in the modified phase corrected algorithm is fundamental for correct depiction of the fat-water intensity gradient at the interface. The original phase correction algorithm produced a number of errors in head images, mostly in areas poorly connected to the remainder of the image (Figure 3). Some of those errors were associated with flow and artefact related phase shifts. The modified algorithm has invariably produced the correct result, as such errors are least likely to propagate when the process starts with lower resolution images. Both algorithms were successful around the tissue-air interfaces in the head, but failed around very large field inhomogeneities, for example, around a dental crown.

Conclusion

An efficient and effective 2-pt phase-correction algorithm for fat and water separation has been demonstrated, with lower sensitivity to noise and good performance surrounding the magnetic field inhomogeneity associated with tissue-air interfaces. The method presented is general and can be applied to other implementations of phase methods for fat-water separation.

References:
1. Dixon, Radiology, 153:189-194, 1984.
2. Ghiglia & Pritt, Two-Dimensional Phase Unwrapping, New York, Wiley, 1998.
3. Ma, Magn. Reson. in Med., 52:415-419, 2004.

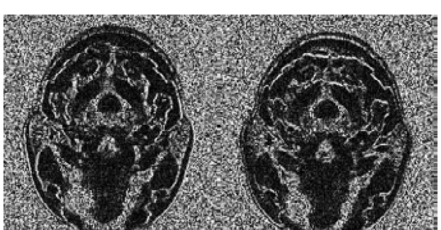

Figure 1. Phase-Gradient based quality maps for directions x and y, demonstrating a low phase gradient at all fat-water interfaces.

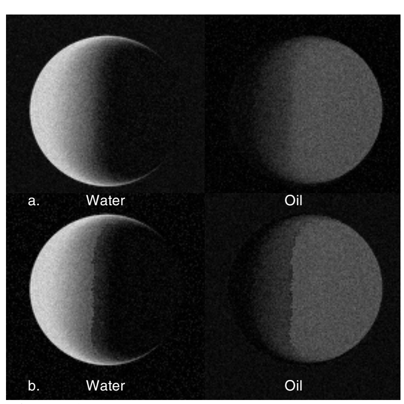

Figure 2. **a**. Modified algorithm on spherical oil-water test object. **b**. Modified algorithm without the final step described in (ii).

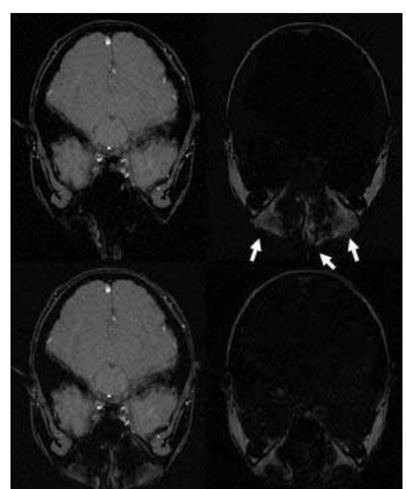

Figure 3. Incorrect fat-water separation with the original algorithm indicated by arrows (above). The modified algorithm (below) produces the correct result.