Regional Iterative Phasor Extraction (RIPE): Effective Phase Correction for Water-Fat Imaging

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Introduction Water-fat imaging [1,2] is a very powerful technique which can be used as high quality fat-suppression to improve contrast for clinical diagnosis. It also has potential to quantify lipids in tissues for studying such conditions as abesity. A key issue for water-fat imaging is phase correction [2] as the original acquired complex images typically contain phase errors due to factors including main magnetic field inhomogeneity, data sampling offset etc. Once the phase errors are indentified and removed from the acquired images, water and fat images can be easily obtained as solutions of a set of linear equations [3]. In this work, a straightforward phase correction technique is described. It uses Regional Iterative Phasor Extraction (RIPE), and is domonstrated with 2-point water-fat imaging data with partially-opposed-phase (POP) [4] acquisition.

Methods The original Dixon method [1] is modified to acquire two complex images, I_1 and I_2, at in-phase and partially-opposed-phase (POP) (e.g. at 135°), denoted as $(0, \alpha)$ respectively. This can be achieved with spin-echo and gradient-echo sequences or other sequences by adjusting the timing parameters [1-4]. The phase of the in-phase image I_1 is first readily removed from both images resulting in images J_1 and J_2 in Eqns.(1) and (2), where P is a smooth spatially varying relative error phasor accumulated only during the time increment between I_1 and I_2 caused by local magnetic field inhomogeneity [4]. The goal of phase correction is to find P and remove it from J_2 so that W and F can be solved. Although P is not completely known, it must be either P_u or P_v given by Eqns.(3) and (4), where B and S are the "big" and "small" chemical components within each pixel which can be robustly obtained [4] from the magnitude of the 2 acquired images $M_1 = |I_1|$ and $M_2 = |I_2|$ as Eqns.(5) and (6). The remaining task is to extract the correct error phasor P from the 2 error phasor candidates P_u and P_v through a Regional Iterative Phasor Extraction (RIPE) procedure described below.

$$J_1 = W + F \quad (1)$$

$$J_2 = [W + F \exp(i\alpha)]P \quad (2)$$

$$P_u = J_2 / [B + S \exp(i\alpha)] \quad (3)$$

$$P_v = J_2 / [S + B \exp(i\alpha)] \quad (4)$$

$$B = \{M_1 + \sqrt{[2M_2^2 - (1+\cos\alpha)M_1^2]/(1-\cos\alpha)}\}/2 \quad (5)$$

$$S = \{M_1 - \sqrt{[2M_2^2 - (1+\cos\alpha)M_1^2]/(1-\cos\alpha)}\}/2 \quad (6)$$

(i) Initialization. In most cases, an initial estimate of the error phasor P_0 can be simply obtained by averaging the 2 error phasor candidates P_u and P_v. For robustness on challenging cases, more sophisticated algorithms can be used to select from P_u and P_v at each pixel to maximize the local magnetization. The P_0 is defined as the selected configuration weighted by a confidence map showing the contrast in local regional magnetization between the selected and unselected configurations.

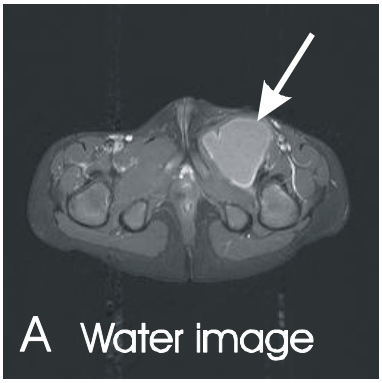
(ii) Smoothing. The initial estimate P_0 is heavily smoothed to produce a smoothed phasor P^S.

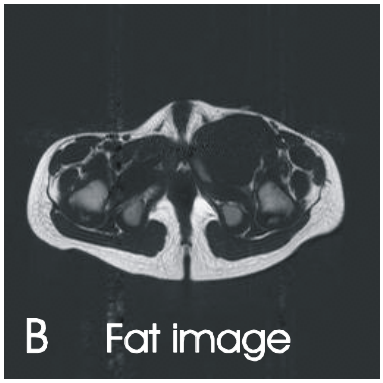
(iii) Comparison. The 2 phasor candidates P_u and P_v are compared with the smoothed phasor P^S, and the one closer to P^S is selected as the next phasor estimate.

(iv) Steps in (ii) and (iii) are repeated until a stabilized phasor P_{stable} is reached.

The stabilized phasor P_{stable} is finally smoothed and removed from J_2, leading to W and F solutions from linear Eqns.(1) and (2).

Results Thousands of water and fat images have been reconstructed by RIPE using 2-point POP acquisition with both spin-echo and gradient-echo sequences at 1.5T and 0.3T, covering various anatomical regions, including head, neck, shoulder, arms, wrists, hands, chest, spine, abdomen, pelvis, thighs, legs, calves, ankles, and feet in axial, sagittal, coronal, and oblique slice orientations. The results are consistently very satisfactory. A typical example case is shown in Figures A and B as uniformly separated water and fat images in lower abdomen. The lesion (arrow) is highlighted in the water image after strong signals from fat are removed.





Discussion Successful phase correction has been achieved by Regional Iterative Phasor Extraction (RIPE), which is in fact a type of Cellular Automata [5,6] where simple local iterations can lead to useful long-range structures. With RIPE, water and fat can be both separated and unambiguously identified, as demonstrated in a large number of *in vivo* cases with 2-point POP acquisition.

References

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