# An optimized region growing algorithm for phase correction in MRI

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**Introduction:** The goal of phase correction in MRI is to determine and remove an erroneous phase $\varphi$ from the acquired complex MRI signal. Since unambiguous determination of $\varphi$ on a pure pixel-level is in general not possible, phase correction usually relies on an assumption that $\varphi$ is "spatially smooth". For certain phase sensitive MRI applications, phase correction can be formulated as selecting a vector represented by $e^{i\varphi}$ from two candidate vectors $A$ and $B$ for each pixel. Determining $e^{i\varphi}$ is to some extent an easier task than determining $\varphi$ because $e^{i\varphi}$ remains unchanged even when $\varphi$ undergoes phase wraps (i.e., with a multiple of $2\pi$ added to or subtracted from its true value). However, the fundamental challenge with pixels of large noise, artefacts, or spatially isolated objects still exists when applying the "spatial smoothness" condition. Further, an ambiguity exists if phase information needs to be propagated between spatially isolated objects. In this work, we developed an optimized region growing algorithm to address some of these limitations. Notably, the algorithm achieves highly reliable and robust region growing by jointly considering the two candidate vectors in selecting the output vector at each step of the region growing. Additionally, an automated segmentation algorithm is built into the process to handle spatially isolated objects. The algorithm was implemented and evaluated for phase correction for in vivo two point Dixon imaging with flexible echo times.

**Method:** The proposed phase correction algorithm used a similar construct of multiple pixel stacks that is described in Ref. (1) to automatically sort out a sequence of region growing so that high-quality pixels are processed before low-quality pixels. Additionally, two major modifications were implemented. First, we jointly considered the two candidate vectors $A$ and $B$ at the each step of region growing to determine an optimal output vector $e^{i\varphi}$. Specifically, for each pixel, we construct two additional vectors $\tilde{A}$ and $\tilde{B}$ as the mirror reflection of $A$ and $B$, relative to $B$ and $A$, respectively, and then calculate the following three angular differences: $\epsilon_1 = |\measuredangle(AA_r^*)| + |\measuredangle(BB_r^*)|$, $\epsilon_2 = |\measuredangle(\tilde{B}A_r^*)| + |\measuredangle(AB_r^*)|$, and $\epsilon_3 = |\measuredangle(BA_r^*)| + |\measuredangle(\tilde{A}B_r^*)|$, where $A_r^*$ and $B_r^*$ are the complex conjugates of the sum of $A$ and $B$ of those pixels that have been processed by the region growing and lie within the neighborhood of the pixel. One of the three vector pairs (i.e., $A$ and $B$, $\tilde{B}$ and $A$, $B$ and $\tilde{A}$) will be selected as the updated vector pair $A$ and $B$ for the pixel if the corresponding angular difference (i.e., $\epsilon_1$, $\epsilon_2$, or $\epsilon_3$) is the minimum of the three angular differences. We considered the three vector pairs because they can be shown to represent all the possible vector pairs regardless whether the pixel is water or fat-dominant and whether $A_r$ or $B_r$ is the vector corresponding to $e^{i\varphi}$. Second, as the region growing progresses, we recorded and monitored the number of the pixels for which each of the three possible vector pairs has been selected and the quality of the pixels being selected during the region growing. Depending on whether an increasing number of pixels have $\tilde{B}$ and $A$, or $B$ and $\tilde{A}$ selected as their updated vector pairs, we can decide whether $A$ or $B$ of the initial seed pixels corresponds to the final desired output vector $e^{i\varphi}$. As the region growing completes processing a high-quality region and moves into noisy background, the quality of the pixels is expected to decrease, which is used to automatically terminate the region growing and start a new region growing from another unprocessed high-quality region (when available).

**Experiment and Results:** We implemented the proposed phase correction algorithm in Matlab (Mathworks, Natick, MA) and evaluated its performance for water and fat separation in two-point Dixon imaging with flexible echo times (2-4). In vivo volunteer images of different anatomical regions were acquired on both 3T and 1.5T scanners (GE Healthcare, Waukesha, WI) using a modified 3D fast spoiled gradient echo sequence with dual-echo readout. The two raw images were first used to algebraically calculate the vector images of $A$ and $B$ (4), which were then used as the input to the phase correction algorithm.

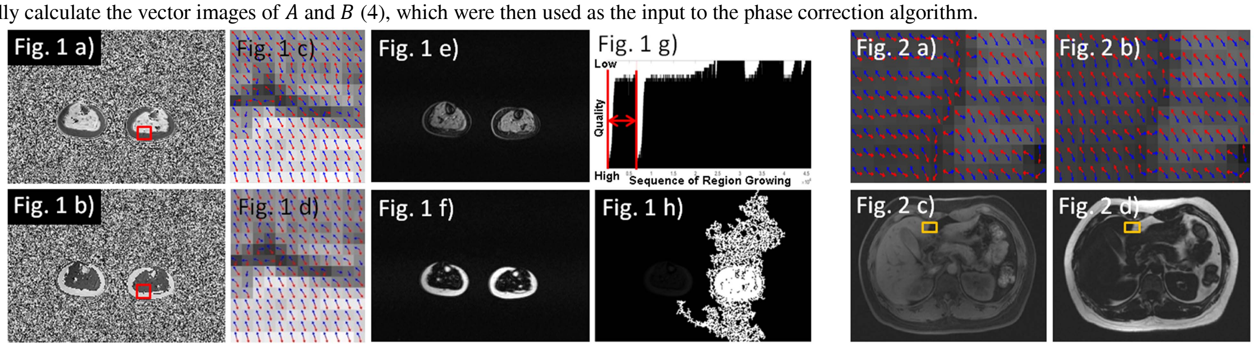


Fig. 1a-b) show the phase map of $A$ and $B$ from axial imaging of the upper legs. A zoom-in view of the two vectors (red for $A$ and blue for $B$) from a small ROI (red boxes in Fig. 1a-b) encompassing both water and fat before and after the phase correction is presented in Fig. 1c-d), respectively. The region growing algorithm was confirmed to successfully identify the correct output vector regardless of whether it started from a water-dominant or fat-dominant pixel. The correctly separated water-only and fat-only images are presented in Fig. 1e-f). Since the image contains two distinct high-SNR regions, the quality of the pixels that was recorded as the region growing progresses (Fig. 1g) automatically terminated the first thread of the region growing (the right leg in Fig. 1h) and started a separate region growing in the other region. Therefore, consistent phase correction was achieved without relying on propagating phase information through the background region. Without any adjustment, the same phase correction algorithm was confirmed capable of consistent water and fat separation in other acquired images (e.g., the abdomen images in Fig. 2).

**Conclusions**: We demonstrated a new phase correction algorithm suitable for two-point Dixon imaging with flexible echo times. The algorithm jointly considers two candidate vectors during each step of region growing and can automatically segment different high-quality regions and independently identify the correct vector map for each segmented region. The algorithm contains very few ad hoc assumptions about the underlying images and is expected to be useful for several important phase sensitive MRI applications.

**References:** [1] Ma J. MRM 2004;52(2):415-419. [2] Xiang QS. MRM 2006;56(3):572-584. [3] Eggers H, et al. MRM 2011;65(1):96-107. [4] Berglund J, et al. MRM 2011;65(4):994-1004.