Autocalibrating Correction of Spatially Variant Eddy Currents for Three-Point Dixon Imaging

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Introduction

Three-point Dixon methods assume in the separation linearity between the common phase of water and fat and the echo time [1]. The contributions to the common phase from field inhomogeneity adhere to linearity. In acquisitions that employ bipolar readout gradients to increase scan efficiency and decrease echo spacing, however, the common phase also includes contributions from eddy currents, which mainly alternate with the polarity of the readout gradient and thus violate linearity. In this work, a novel two-point Dixon method is applied to subsets of data from bipolar three-point acquisitions to calibrate a 3D correction of eddy current-induced phase errors and to facilitate in this way a homogeneous fat suppression over large volumes.

Methods

The proposed eddy current correction is schematically illustrated in Fig. 1. The three images obtained by separately reconstructing the data from each echo are first decimated by a factor N. A two-point Dixon method is then applied to two pairs of them (1+2, 3+2). We employed the method outlined in Ref. [2] to allow arbitrary echo spacings. It provides, similar to the method described in Ref. [3], a phasor map that reflects the evolution of the common phase of water and fat modulo 2π between the two considered echo times. For a bipolar acquisition, the two resulting phasor maps P_{12} and P_{32} may be described by

$$P_{12} = P \cdot \Delta P \quad \text{and} \quad P_{32} = P^{*} \cdot \Delta P,$$

where P and ΔP are the contributions due to field inhomogeneity and eddy currents, respectively. Their product

$$\Delta P^2 = P_{12} P_{32}$$

permits determining the phase error map ΔP. Depending on the range of the phase error, an unwrapping may have to be applied to ΔP^2 in this process. We used the algorithm detailed in Ref. [4] for this purpose. Finally, the phase error map is upsampled by a factor N, and its complex conjugate is multiplied with the image from the second echo. A standard three-point Dixon method [1] may then be applied to this corrected image and the original images from the first and the third echo.

Abdominal imaging on volunteers was performed on 1.5 T scanners (Philips Healthcare, Best, Netherlands) with 16 or 32 element receive coils and a bipolar 3D spoiled multi-gradient-echo sequence. Typical protocol parameters included a FOV of 370 x 260 x 240 mm^3, a voxel size of 1.5 x 1.5 x 3.0 mm^3, a flip angle of 10°, a TR/TE_1/ΔTE of 4.8/1.3/1.1 ms, and a 4-fold (2 x 2) acceleration by parallel imaging. Scans were completed in single breath-holds in less than 20 s. A 1D correction of eddy currents was optionally calibrated in a brief preparation phase measurement and applied prior to all further processing.

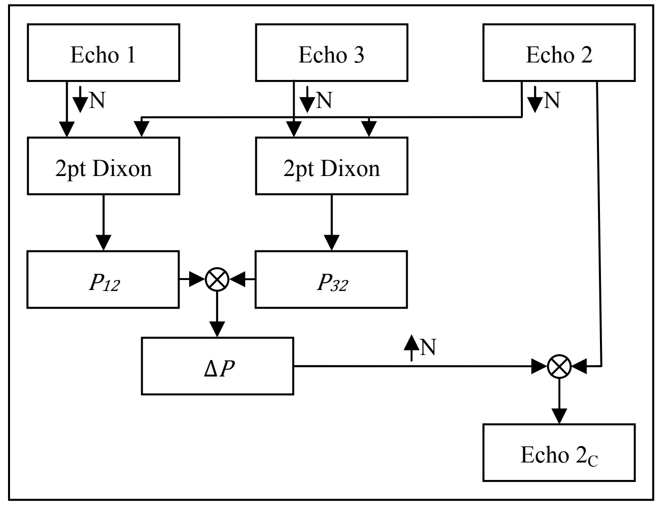

Fig. 1. Schematic illustration of the proposed eddy current correction, which precedes a standard three-point Dixon method that is applied to the original images from the first and the third echo and the corrected image from the second echo.

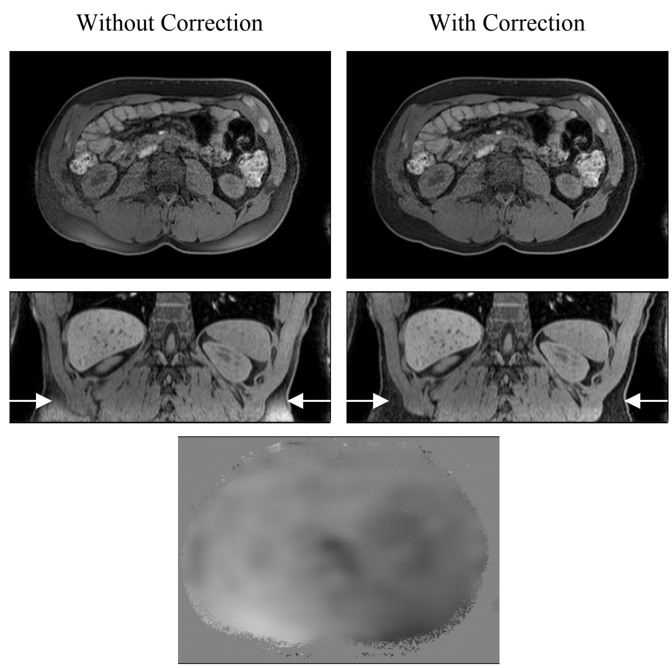

Fig. 2. Selected water images, produced without and with the proposed eddy current correction, in transverse and coronal orientation, and the corresponding phase error map, scaled to a range of ±π. The arrows in the coronal slice indicate the position of the transverse slice.

Results

The benefit of the proposed eddy current correction is demonstrated in Fig. 2. The displayed transverse and reformatted coronal slices clearly show that variations of the eddy current-induced phase errors in the phase encoding directions only become significant towards the edges of larger volumes. If ignored these variations lead to substantial leakage of fat signal into the water images. The proposed eddy current correction restores a homogeneous fat suppression across the entire FOV.

Conclusions

Three-point Dixon methods are susceptible to phase errors that alternate between odd and even echoes in bipolar acquisitions. In first approximation, the variations of these phase errors are limited to the frequency encoding direction and are easily removed prior to the separation based on a short calibration measurement. This approximation becomes inaccurate for large volumes, however. While mapping the phase errors in 3D would require substantial scan time, the proposed autocalibrating correction relies on the available imaging data only. Since it is applied on a low resolution level, the loss in SNR is negligible, and the occasionally required phase unwrapping remains simple and robust. It may also be an attractive alternative to fitting the phase errors as a nuisance parameter in multi-point Dixon imaging [5].

References

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