Dual-Echo Dixon Imaging with Unrestricted Choice of Echo Times

H. Eggers1, B. Brendel1, A. Duijndam2, and G. Herigault2

1Philips Research, Hamburg, Germany, 2Philips Healthcare, Best, Netherlands

Introduction

Two-point Dixon methods are particularly attractive in rapid imaging applications. However, they commonly restrict the choice of echo times by requiring at least one of them being in phase [1,2]. This compromises their scan efficiency and renders them sometimes even slower than three-point Dixon methods [3]. In this work, a novel two-point Dixon method is described that basically eliminates all constraints on the echo times, and its performance is compared to that of existing two-point Dixon methods in abdominal imaging.

Methods

The composite signal $S$ in image space at echo time $TE$ is modeled by

$$ S = (W + Fe^{i\theta})e^{i\phi}s, $$

where $W$ and $F$ are the water and fat signal in image space, $\theta$ is the dephasing angle between them, and $\phi$ is a common phase. First, potential values of the phasor that corresponds to the phase error $\Delta \phi := \phi_2 - \phi_1$ are calculated. For this purpose, a major and a minor signal component are derived from the magnitude of $S$ at the two echo times [2]

$$ M_{1/2} = \frac{1}{2} \left| \frac{S_1^2 - |S_1|^2 - |S_2|^2}{\cos \theta_2 - \cos \theta_1} \right| + \frac{1}{2} \left| \frac{S_1^2 - |S_1|^2 + |S_2|^2}{\cos \theta_2 - \cos \theta_1} \right|. $$

and the conjugate complex product of the signal equation for the two echo times is solved, yielding

$$ e^{i\Delta \phi/1/2} = \left( \frac{S_1 S_2}{(M_{1/2} + M_{1/2} e^{i\phi_2})(M_{1/2} + M_{1/2} e^{i\phi_1})} \right). $$

Then, one of these values is selected based on the assumption of spatial smoothness of the phasor. Any of a number of existing strategies may be applied for this purpose [1,2,4]. Finally, $W$ and $F$ are re-estimated given $S_1$, $S_2$, and the phasor. Either they are considered as real and the system of equations

$$ W^2 + 2WF \cos \theta_{1/2} = |S_{1/2}|^2, $$

$$ W^2 + F e^{i\Delta \theta} + WF (e^{i\phi_1} + e^{-i\phi_1}) = S_1 S_2 e^{-i\Delta \phi}, $$

is solved, or they are considered as complex and the two signal equations are solved for $W = W e^{i\phi_1}$ and $F = F e^{i\phi_1}$.

Abdominal imaging on volunteers was performed on 1.5 T and 3.0 T scanners (Philips Healthcare, Best, Netherlands) with 16 and 32 element receive coils and a 3D spoiled multi-gradient-echo sequence. Typical protocol parameters included a coverage of 370 x 260 x 240 mm$^3$, a slice thickness of 3 mm, and a flip angle of 10°. Scans were completed in single breathholds in less than 20 s.

Results

The relative noise in water images produced with the proposed method is quantified for a range of echo times in Fig. 1. The shown simulated values reflect the worst case, in which no spatial smoothing of the phasor is performed, for a selected water-fat ratio. They decrease towards shorter and longer echo spacings, as known from existing methods [2], and additionally close to the two diagonals defined by $\theta_1 + \theta_2 \mod 2\pi = 0$.

In Fig. 2, the proposed method (lower row) is compared to existing methods (upper row) [1,2] at 1.5 T. Given the minimum TR for an in phase echo time, it allows the use of lower bandwidths and thus provides up to 60% more SNR in this case. Alternatively, it permits the use of shorter TRs and thus accelerates scans up to 1.6-fold in this case (1.3-fold in the shown example).

The freedom of choice is exploited to enhance the spatial resolution at 3.0 T in Fig. 3. While there is no significant penalty for an in phase echo time at 1.5 mm, it gets substantial at 1.0 mm (20% longer TR) and even prohibitive (70% longer TR) if additionally an out phase echo time is demanded [1].

Conclusions

Removing the restrictions on the choice of echo times that are imposed by existing two-point Dixon methods provides more flexibility in the selection of protocol parameters and thus enables shorter scan times, higher spatial resolution, and increased SNR in rapid imaging applications.

References