Highly accelerated k-t SENSE using large coil arrays

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Introduction

In dynamic MR imaging, there is a trade-off between the achievable spatial and temporal resolutions. In order to relax this trade-off and to accelerate image acquisition, several techniques which exploit spatiotemporal correlations jointly with coil encoding have been proposed [1-3]. Among them, *k-t* SENSE has been proven very effective [3]. However, it has been noted that with increasing acceleration factors small dynamic image features may become blurred [3-5]. This, in part, relates to the coarse spatial resolution of the training data. Accordingly, partial volume effects may cause underestimation of small signals at high temporal frequencies. With higher acceleration factors, significant signal contributions from different spatial positions and temporal frequencies start to overlap, thereby accentuating any deficits in the training data.

When using antenna arrays with a large number of independent receive channels, the encoding capability of the array may be exploited to partially alleviate the role of training data, leading to improved temporal fidelity at the expense of increased noise. This can be achieved by adding a constant signal offset to the training data [4]. However, the efficacy of this approach decreases with increasing reduction factors due to excessive noise amplification from coil encoding. Another strategy to improve the accuracy of reconstruction is to choose optimized sampling patterns in data acquisition. In [5], general guidelines for designing sampling patterns which provide maximum main lobe separation of signal replica in the spatial-temporal frequency domain have been derived. With these patterns each k-space point is visited at least once over time making it possible to calculate coil sensitivity information from the undersampled data [1,3].

In this work, sampling patterns are studied which provide increased separation of signal replica along the temporal frequency dimension by skipping spatial phase-encodes entirely. Given that certain spatial phase-encodes are not acquired at all, separate coil calibration data are required. It is shown that the modified sampling patterns provide increased reconstruction accuracy of dynamic features from highly accelerated cine 2D imaging of the heart.

Methods

Short-axis and four-chamber view images were obtained using a cardiac gated cine balanced SSFP sequence on a Philips 1.5T system (Philips Medical Systems, Best, The Netherlands). Scan parameters were: matrix: 256x160, FOV: 350x260 mm^2, T_R/T_E: 3.8/1.9 ms, flip angle: 60°. A 32 channel cardiac coil array was used for signal reception. Coil sensitivity information was extracted from a separate calibration scan. In *k-t* SENSE the sampling patterns were modified to allow mixing of multiple spatial signals for a given temporal frequency per unit cell in the spatial-temporal frequency domain. Figure 1 depicts such a modified sampling pattern for 10- and 16-fold acceleration along with the conventional sampling pattern. In the modified patterns shown, only every other spatial phase-encode line was acquired providing twice the sampling density along the temporal frequency dimension. To allow for a quantitative assessment of the reconstruction error, fully sampled data sets were obtained in addition to undersampled data. These data were then decimated according to the sampling patterns shown, to simulate accelerated data acquisition. In *k-t* SENSE eleven central profiles were sampled densely to derive training information. Images were then reconstructed according to the equations given in [3].

Results

Figure 2 compares spatiotemporal plots of a 2D short-axis image series along the line indicated of a) a fully sampled acquisition (reference), b) 10x *k-t* SENSE using the regular pattern shown in Figure 1, and, c) *k-t* SENSE using the modified sampling pattern (5x2 *k-t* SENSE). Arrows indicate highly dynamic features which appear less blurred with 5x2 sampling compared to regular 10x sampling. This observation is confirmed by a lower root-mean-square (RMS) reconstruction error as a function of cardiac phase (Figure 3). It is seen that modified sampling results in a reduced level and variation of the RMS error during rapid motion of the heart, at the expense of a slightly increased error during less dynamic phases.

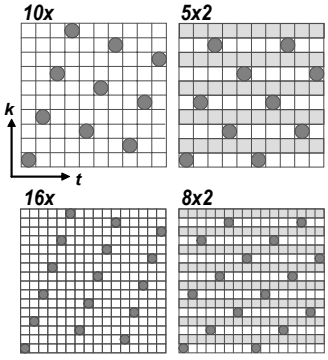

***Figure 1**. 10x and 16x undersampling using regular sampling pattern (left column), and modified pattern with skipped spatial phase-encodes (shaded rows) (right column). Gray dots indicate sampled positions.*

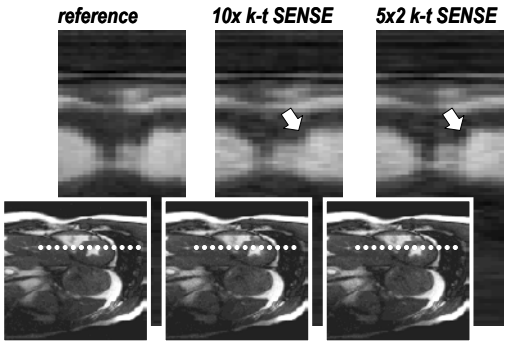

***Figure 2**. Comparison of 10x and 5x2 k-t SENSE relative to the fully sampled reference scan. Spatiotemporal plots are taken along the dotted line indicated. Arrows highlight highly dynamic image features. It seen that 5x2 k-t SENSE results in improved temporal fidelity.*

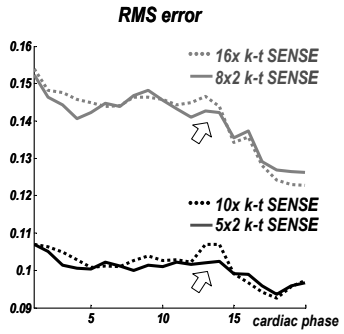

***Figure 3**. Relative reconstruction error for 5x2 and 8x2 k-t SENSE (solid lines) relative to regular 10x and 16x undersampling. Modified sampling yields lower errors during phases of rapid motion at the expense of slightly increased error during less dynamic periods.*

Discussion

Modified sampling for highly accelerated *k-t* SENSE has been demonstrated. Omission of entire phase-encodes allows separating signal replica further along the temporal frequency dimension thus improving temporal fidelity at the expense of increased noise from coil encoding during less dynamic phases. Further work will be dedicated to exploring high acceleration factors in 3D.

References

[1] Kellman P, et al., MRM 2001;**45**: 846-852; [2] Madore B, et al., MRM 2004;**52**: 310-320; [3] Tsao J, et al., MRM 2003;**50**:1031-1042; [4] Kozerke S, et al., Proc. ISMRM 2005, 2454; [5] Tsao J, et al. MRM 2005;**53**: 1372-1382