Dynamic imaging methods assessed with a 2D MTF approach

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Introduction: Dynamic imaging has been a rapidly evolving field over the past few years. As new methods are being introduced, reliable performance assessment strategies would be highly desirable. Placing ROIs near moving features and comparing the time-varying signal to a known 'truth' has been one common way of testing method performance. Calculating the artifact energy in difference images is also a common approach. Although undeniably very useful, these tests tend to be anecdotal in nature, as a method that works well on a given object may not work as well on a different object. A 2D modulation transfer function (MTF) approach is presented here, whereby the response of a method to all combinations of spatial and temporal frequencies gets captured and displayed. The approach was tested on two dynamic imaging methods, *kt*-SENSE [1] and UNFOLD-SENSE [2], over a range of acceleration factors.

Methods: Data from a simulated object featuring non-zero signal at all spatial/temporal frequencies within the measured bandwidths was fed into *kt*-SENSE and UNFOLD-SENSE algorithms. Reconstructed signal at each f-k_y locations was compared to the known 'truth', to generate 2D MTFs. Results from different *x* locations were averaged.

With *kt*-SENSE, Tsao *et al*. introduced the idea of using prior knowledge from a training scan for regularization purposes. While most dynamic imaging methods use prior knowledge in the form of a region of support for the non-aliased signal, *kt*-SENSE uses actual images instead (see Fig. 1). This prior knowledge is included into a matrix **M**, and the expression for the SENSE unfolding matrix [3], $\mathbf{U}=(\mathbf{S}^H \mathbf{\Psi}^{-1} \mathbf{S})^{-1} \mathbf{S}^H \mathbf{\Psi}^{-1}$, becomes $\mathbf{U}=(\mathbf{S}^H \mathbf{\Psi}^{-1} \mathbf{S} + \mathbf{M}^{-2})^{-1} \mathbf{S}^H \mathbf{\Psi}^{-1}$. UNFOLD-SENSE was modified to use this latter expression, with the **M** matrix.

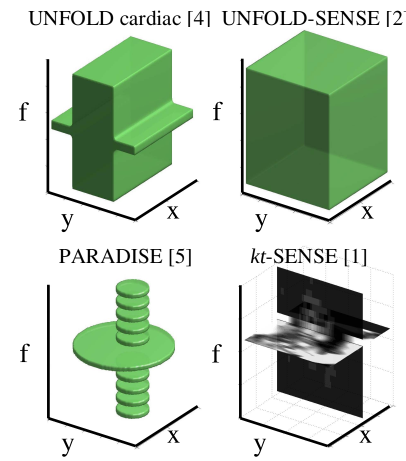

Fig. 1

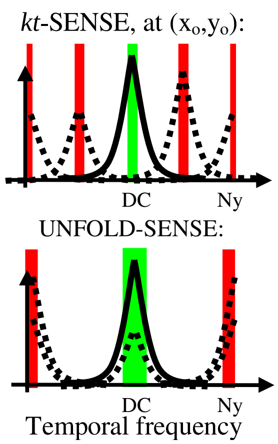

Fig. 2

Another significant difference between *kt*-SENSE and UNFOLD-SENSE involves the slope in *kt*-space. With *n* the skip factor and Δt the temporal resolution, UNFOLD-SENSE uses a steeper slope of $n\Delta k_y/2\Delta t$, while *kt*-SENSE uses a gentler slope of about $\Delta k_y/\Delta t$. Figure 2 represents 1D temporal frequency spectra at one image pixel that is corrupted by aliasing. The gentler slope generates smaller displacements along the *f* axis, distributing overlapped spectra throughout the bandwidth (Fig. 2, top). The steeper slope displaces spectra farther along *f*, and as wraparound occurs from negative to positive frequencies and vice-versa, two 'piles' get formed at DC and at Nyquist (Fig. 2, bottom). Both reconstruction methods involve using a reduced acceleration factor near DC (green bands), and both have difficulties recovering the small non-aliased signals that get superposed with potentially intense aliased signals (red bands). The main advantage of the sampling scheme used in *kt*-SENSE is that a lower acceleration can be used at DC (1 vs. *n*/2 in Eq. 11 of [2]), while the advantage of the '2-pile scheme' is that only at Nyquist, all the way to the edge of the resolved bandwidth, does small non-aliased signal gets overwhelmed by intense aliased signal (see red bands).

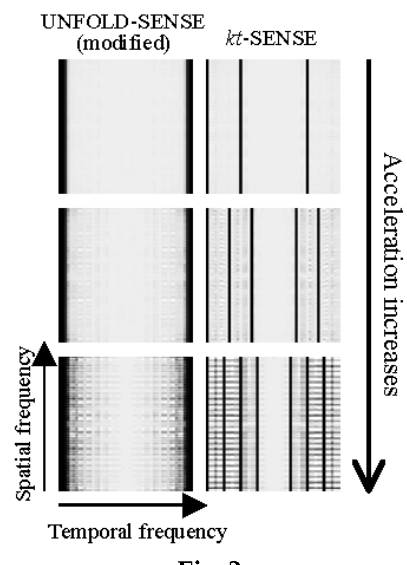

Fig. 3

Results: 2D MTFs were generated for skip factors of 4 (Fig. 3, top row), of 6 (middle row) and of 8 (bottom row), both for *kt*-SENSE and UNFOLD-SENSE, using a 10-line training scan. When using the **M** matrix in both reconstructions, differences in the MTFs from both methods have mostly to do with the effect explained in Fig. 2, as both methods have difficulties recovering some temporal frequencies. The content of these missing frequency regions could of course be filled-in through interpolation, if so desired.

Discussion: An MTF is typically meant to be object-independent, and should represent only the imaging strategy itself. But when reconstruction methods involve prior knowledge about the object, full object independence may not be possible. Adding noise to the data used here would seem to further increase object dependence. As noise is added, the measured MTFs are degraded, and frequencies with the smallest signal in a given object tend to be most affected.

Conclusion: A procedure for assessing the performance of dynamic imaging methods was proposed, and tested in two methods.

[1] Tsao *et al*., MRM 2003;50:1031-42. [2] Madore, MRM 2002;48:493-501. [3] Pruessmann *et al*., MRM 1999;42(5):952–62.
[4] Madore *et al*., MRM 1999;42:813–26. [5] Sharif *et al*., ISMRM 2007:151.

Support from GE Healthcare, U41 RR019703 and R01 HL073319 is acknowledged.