Comparison of TSENSE, k-t SENSE and PINOT Fast Imaging Methods on Cine MRI

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INTRODUCTION

A variety of methods have been proposed for accelerated cardiac MRI acquisition combining prior knowledge about spatiotemporal redundancy and receiver coil sensitivity maps, including TSENSE[1], *k-t* SENSE[2] and PINOT[3] (Parallel Imaging and NOquisT). However, the relative benefits and limitations of each method have not been adequately analyzed and compared. The purpose of this study is to compare these three fast imaging reconstruction methods on real cardiac cine images. All the methods are implemented in the phase encoding dimension only.

TSENSE reconstruction combines UNFOLD[4] (R=2) with SENSE[5] (R=2) to achieve an acceleration factor of 4. First, interleaved *k*-space sampling shifts two aliased components to the temporal band edge; the aliases are subsequently filtered using a low pass Fermi filter. Then SENSE is applied to each frame to separate the remaining two aliased components with two or more coils. *k-t* SENSE allows a reduction in data acquisition by packing the image signals more tightly in the spatial-temporal frequency (*x-f*) space. The signal covariance of aliased components can be captured from a separate low-resolution training data set. The true signal is retrieved from aliased components. PINOT (which we introduced earlier under the name "No'nSENSE"[3]) combines the direct-inversion methods SPACE-RIP[6] for parallel imaging and Noquist[7] for spatiotemporal redundancy when parts of the field of view (FOV) are static.

MATERIALS AND METHODS

Fully sampled MRI data were acquired on a 1.5 Tesla General Electric Signa TwinSpeed scanner with an 8-element cardiac coil. The short axis data set (TE=2.0 ms, TR=4.1 ms, flip angle=45°, FOV=35×35 cm, slice thickness=12 mm) has 224 phase encodings and 256 frequency encodings, and 16 temporal frames. A separate reference scan was obtained to calculate the sensitivity maps. By first filtering high frequency components in *k*-space for each coil, each smoothed coil image was divided by the square rooted sum of squares of all coil images to obtain the sensitivity maps. All the reconstructions were performed with MATLAB R2007a (The Mathworks, Natick, MA) on a Quad Core Xeon 2.66GHz computer with 16GB of RAM.

We applied a reduction factor 4 for TSENSE and *k-t* SENSE. For the latter, 4 profiles were used in addition for the training stage. For PINOT, we used a reduction factor of 2 for SENSE, assuming 50% dynamic FOV for Noquist. The net reduction factors were 4 for TSENSE and 3.73 for *k-t* SENSE and PINOT. The fully sampled data were decimated as follows: TSENSE's undersampled acquisition repeats every other frame (1,3,1,3, etc.). The sampling scheme for *k-t* SENSE acquisition repeats every fourth frame (1,2,3,4, etc.). PINOT's undersampled acquisition is based on Noquist's sampling scheme expanded by the SENSE sampling scheme[3,7].

RESULTS

Reconstruction results are shown in Figure 1. All three methods yielded acceptable image quality. TSENSE and *k-t* SENSE both displayed edge blurring at myocardial boundaries during systolic contraction, and some aliased ghosting of this artifact. PINOT showed visibly lower edge artifact levels, but at some penalty of higher random noise level, especially in the dynamic region of images. Noise statistics are presented in Table 1 in five regions of interest (ROI) at different locations shown in Figure 1. For PINOT, regions 1, 2 and 3, are in the dynamic FOV, 4 and 5 are in the static FOV.

DISCUSSION AND CONCLUSIONS

A comparison of three fast imaging methods was performed in real data. Results correspond well with an earlier comparison of Noquist and UNFOLD. TSENSE has higher SNR than PINOT or *k-t* SENSE, but there is a trade-off between SNR and Fermi filter coefficients, and the optimal choice of the filter is image-dependent. Fewer overlaps between aliased signals make *k-t* SENSE work better than TSENSE for higher reduction factors. Because the high spatial frequencies are not acquired with the training data in *k-t* SENSE, the reconstruction is less influenced by noise but tend to suffer from partial volume effects with signal underestimation at higher temporal frequencies. PINOT preserves full spatiotemporal resolution and retains edge information better than TSENSE and *k-t* SENSE since it does not apply any temporal or spatial smoothing during reconstruction. However, PINOT adds computational burden to image reconstruction and has an added cost of accumulated SNR penalty. If the imaging system has limited SNR, TSENSE and *k-t* SENSE may be more suitable methods. If a SNR trade-off can be afforded, PINOT may be the better choice for preservation of image details especially in fast motion images.

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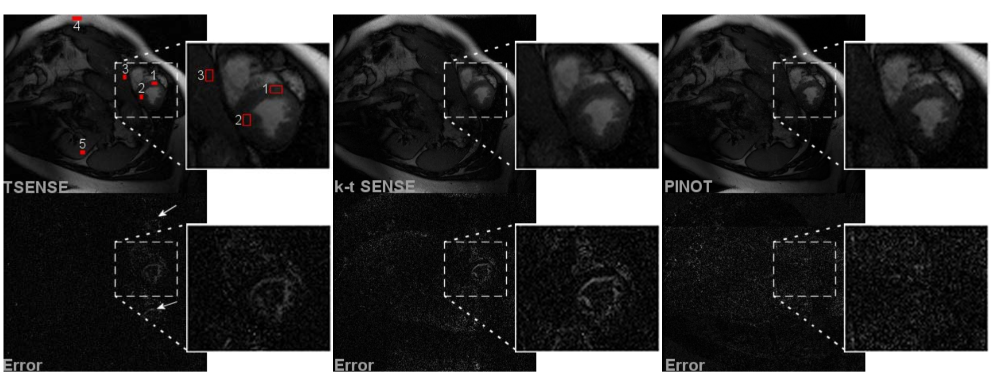

Table 1. Regional Standard Deviations in Image Noise

ROI	1	2	3	4	5
Full-grid	0.11	0.09	0.08	0.22	0.10
TSENSE	0.20	0.14	0.12	0.25	0.15
k-t SENSE	0.16	0.23	0.13	0.26	0.12
PINOT	0.23	0.20	0.19	0.27	0.11

Figure 1. Comparison of reconstruction by TSENSE (left), *k-t* SENSE (middle) and PINOT (right) using real MRI data acquired with an 8-channel cardiac coil. (of which only 5 were used for best SNR). The 13th reconstructed frame image (top) is shown here for all reconstructions. Corresponding error images (bottom) are displayed as well, amplified by a factor of 5 for visibility. Zoomed images are shown to reveal details in the heart. TSENSE image artifacts outside ROI are marked by white arrows. The 5 ROIs shown in red are for noise statistics.