Image Reconstruction of Variable Density undersampled EPI Images

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Introduction Compressive Sensing (CS) has been applied in MRI image reconstruction for undersampling during acquisitions to reduce scan time while preserving the image quality [1-3]. Its success in angiogram and cine cardiac image reconstruction suggests that the theory is applicable to other MR images with transformed domain sparsity. Single-shot Echo Planar Imaging (SS-EPI), in principle, has poorer SNR and spatial resolution due to the rapid acquisition of the entire k-space in one shot. With the use of CS, it is possible to reduce the number of k-space profiles collected per excitation while preserving the EPI image quality. Thus, larger slice coverage or higher spatial resolution can be obtained, which can be traded for higher temporal resolution. In this work, we demonstrate the use of the CS method on EPI imaging. The image quality recovered by the proposed method was compared with 2 typical scan time reduction methods, (i) Half NEX and (ii) scan percentage reduction. In addition, we investigated the feasibility of applying CS to BOLD functional MRI (fMRI).

Method Data were collected in a 3T whole body MRI system (Achieva R1.5, Philips Medical System, Best, The Netherlands). Full-sampled k-space data were obtained using a single shot FE-EPI sequence with parameters: TR/TE=3000/30ms, α=90°, resolution=3.75x3.75x4mm^3, FOV 240mm. For CS reconstruction, undersampling was achieved offline in the full-sampled k-space along the phase encoding direction with a higher weighting at the center region. The weighting was calculated as a probability density function with a power of distance from the k-space center. According to some previous works [1,3,4], this variable density (vd) undersampling pattern is more efficient than random undersampling for CS in MRI, because of the concentration of low frequency components in the central k-space. The EPI image was reconstructed by solving the optimization problem:

$$\textit{minimize } \|TV(m)\|_1 \quad \textit{subject to } \Phi m = y \qquad (1)$$

where m is the reconstructed EPI brain image, Φ is the variable density undersampled Fourier matrix and y is the measured k-space data. We propose using Total Variation (TV) as the sparsity transform for CS EPI reconstruction. Comparing with anatomical imaging, EPI has a poorer contrast due to its intrinsic acquisition method and thus it is characterized as spatial gradient sparse (i.e. the finite difference of the image is sparse). For Half NEX and scan percentage reduction, the upper half and peripheral of k-space of the full-sampled data were discarded respectively. The missing data were recovered by finding the complex conjugate in Half NEX and by zero-fillings in scan percentage reduction. For a fair comparison, the number of samples was identical in all 3 types of reconstruction schemes. Furthermore, we investigate the feasibility of applying CS to fMRI. A normal subject was recruited for a bilateral finger tapping task with a 60 dynamics block design paradigm, using the same imaging parameters as above. Full-sampled k-space data were collected and undersampling with CS reconstruction was done offline in every dynamic with a 50% vd pattern. The CS reconstructed data and the original data were analyzed with SPM2. Activation maps and the Student's t-values from the 2 set of data were compared.

Results Fig. 1 shows the results obtained from (a) original full-sampled image, (b) Half NEX, (c) scan percentage reduction and (d) CS reconstruction with the use of 62.5% variable density sampling. The CS reconstructed image is comparable to the original full-sampled data and scan percentage reduction, with the fine details visible (yellow circle). Table 1 shows the mean square errors (MSE) of different methods when compared with the full-sampled data. CS reconstruction outperforms the other 2 methods in all percentage of undersampling. Half NEX is not applicable in 40% sampling due to its fundamental reconstruction principle. Fig. 2 shows the activation maps computed from (a) full-sampled and (b) 50% vd CS reconstructed data overlaid on corresponding EPI images. Their activation maps have nearly identical patterns and spatial locations. The volume of activations is 63 and 62 voxels for Fig. 2a and Fig. 2b respectively, with an error of 1.59%. The Student's t-values obtained at the suprathreshold voxel (crosshair) are also similar (t = 7.34 vs. t = 7.29), with an error of 0.68%.

Discussions We demonstrated the application of CS to EPI image recovery. The quality of the CS recovered image is comparable to the original one, with the fine details recovered. With only 50% of samples, the statistical analysis still reveals similar activation maps with minimal mis-localization.

CS outperforms the other 2 reconstruction techniques as evaluated by MSE. At 40% of sampling, CS has an RMSE error of 4.0% only.

Future directions include true undersampling during acquisition for CS reconstruction, design of optimal sampling patterns and investigation of its possibility to reduce geometric distortion and to increase spatial resolution due to a shorter EPI trains in undersampling.

References

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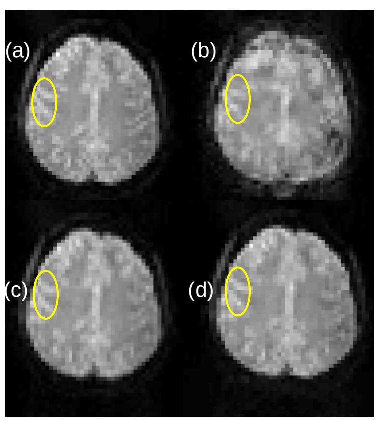

Fig.1 Comparisons of reconstructed EPI images with 62.5% samplings. (a) Original, (b) Half NEX, (c) Scan percentage reduction and (d) CS variable density.

	CS (TV)	Scan % ↓	Half NEX
40%	0.0016 (4.0%)	0.0034 (5.83%)	--
50%	0.0014 (3.74%)	0.0030 (5.48%)	0.0206 (14.35%)
62.5%	0.0010 (3.16%)	0.0011 (3.32%)	0.0030 (5.48%)

Table 1 MSE (RMSE) of the 3 reconstruction schemes with different percentage of samplings (100% is full samplings).

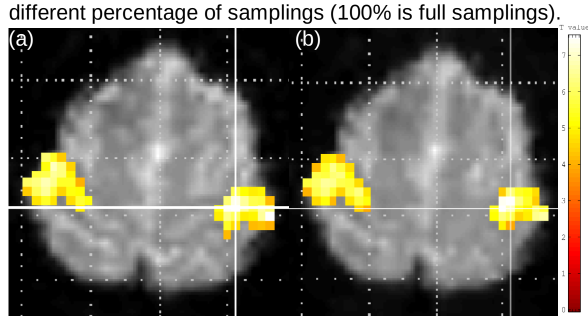

Fig. 2 Statistical activation maps with overlays. (a) Original and (b) CS reconstructed with 50% variable density undersampling. The t values at the crosshair are (a) 7.34 and (b) 7.29 respectively.