Super-resolved enhancing and edge deghosting for spatiotemporally encoded single-shot MRI

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Target audience

The target audience is basic scientists and clinical scientists who are interested in ultrafast imaging.

Purpose

Spatiotemporally encoded (SPEN) single-shot MRI is an ultrafast MRI technique proposed recently, which has great advantages in resisting field inhomogeneity and chemical shift effects compared to the echo planar imaging (EPI).[1] Super-resolved (SR) reconstruction is adopted to compensate the inherent low resolution. Due to insufficient sampling rate, SR image is challenged by aliasing artifacts and edge ghosts. The existing SR algorithms always compromise in spatial resolution to suppress these undesirable artifacts.[2,3] In this abstract, we proposed a novel SR algorithm termed super-resolved enhancing and edge deghosting (SEED). By exploiting the relationship between aliasing artifacts and real signal, our algorithm can eliminate the aliasing artifacts without spatial resolution loss. According to the trait of edge ghosts, total variation (TV) and high-pass filter are employed to extract the prior knowledge of edge ghosts. By combining the prior knowledge with compressed sensing (CS), our algorithm can efficiently reduce the edge ghosts and provide better image quality.

Methods

The point spread function (PSF) of SPEN approach can be expressed as:

$$PSF(y,\varepsilon) = N\sum_m \text{sinc}\left[\frac{\gamma G_a T_a}{2}\left(\varepsilon + m\frac{2N}{\gamma G_a T_a}\right)\right]\cdot E(y,\varepsilon) \quad (1)$$

where G_a and T_a are magnitude and duration of the decoding gradient respectively. N is the sampling point along phase encoding dimension. $E(y,\varepsilon)$ is the additional phase term derived from the quadratic phase encoding. Due to the additional phase term, the relationship between aliasing image $\boldsymbol{\rho}_\mathbf{a}$ and aliasing-free image $\boldsymbol{\rho}$ can be expressed as:

$$\mathbf{E}\boldsymbol{\rho} = \boldsymbol{\rho}_\mathbf{a} \quad (2)$$

where $\mathbf{E}$ is related to the additional phase term. However, aliasing-free image is degraded by the edge ghosts. According to the trait of edge ghosts, TV and high-pass filter is utilized to extract the prior knowledge of edge ghosts. Combined CS with the prior knowledge, $\boldsymbol{\rho}$ can be calculated as followed:

$$\arg\min \left\|\mathbf{W}(\mathbf{E}\boldsymbol{\rho} - \mathbf{F_u S})\right\|_2^2 + \lambda_1\left\|\boldsymbol{\Psi\rho}\right\|_1 + \lambda_2\left\|TV(\boldsymbol{\rho})\right\|_1 \quad (3)$$

where $\mathbf{F_u}$ stands for the FT-based reconstruction of acquired signal $\mathbf{S}$, $\boldsymbol{\Psi}$ is a sparsifying transform. λ_1 and λ_2 are regularization parameters. $\mathbf{W}$ indicates the prior knowledge of edge ghosts. The flowchart of SEED is given in Fig. 1.

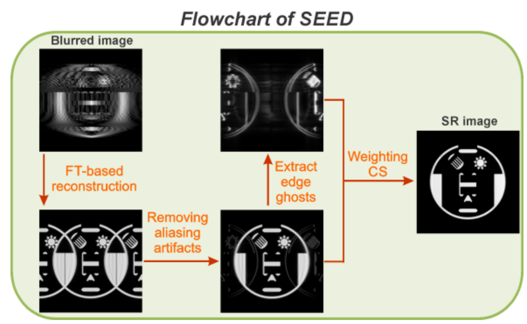

FIG. 1. Flowchart of SEED algorithm

Results

Simulations were carried out with the SPROM software developed by our group. Experiments were performed on a Varian 7.0 T MRI system using a quadrature-coil probe. The experimental sample was an *in vivo* rat. The FOV was 50 × 50 mm^2. The matrix size was 64 × 64. For simulation and axial rat brain experiments, the bandwidth and duration of chirp pulse was 32kHz/4ms. For sagittal rat brain experiments, the bandwidth and duration of chirp pulse was 64kHz/4ms. The EPI image with full sampling and the SR SPEN image reconstructed by hybrid scheme[2] were used as references to evaluate the efficiency of SEED. The results are shown in Fig. 2.

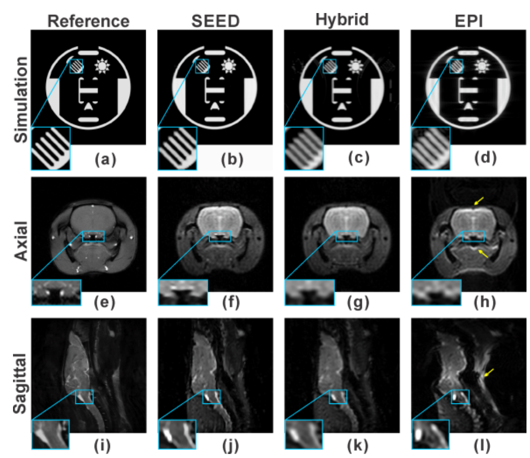

FIG. 2. Images from simulation (a~d) and *in vivo* rat brain experiments (e~l).

Discussion

From the in vivo rat brain experiments we can see that EPI images suffer from severe geometric distortion, as indicated by yellow arrows, which may confuse the identification of details. The SPEN approach possesses better immunity to inhomogeneous field and can effectively alleviate the geometric distortion. The zoom-in regions in Fig. 2 indicate that the SEED can restore a better edge compared to the hybrid scheme and EPI. The reason why SEED algorithm can achieve superior resolution is that SEED algorithm makes full use of the whole acquisition data without discarding any information during the SR reconstruction and extends the digital resolution without interpolation to the acquired signal[2] which will inevitably degrade the sharp edge.

Conclusion

The robustness of SEED is experimentally demonstrated. The results indicate that the SEED can provide better spatial resolution compared to the state-of-the-art SR reconstruction algorithms in SPEN MRI.

Acknowledgement

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References

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