Accelerating MRI by Skipped Phase Encoding and Edge Deghosting (SPEED)

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Introduction

MRI can be accelerated by parallel imaging methods such as SMASH [1] and SENSE [2]. However, parallel imaging requires multiple RF coils as well as separate measurements of their sensitivity profiles which often impose technical burdens on hardware, MRI sequence, and image reconstruction. This paper investigates the possibility of reducing scan time by a simpler approach using only a single coil and minor modification of standard pulse sequences. The method uses Skipped Phase Encoding and Edge Deghosting and thus is termed SPEED.

Methods

It is well known that phase encoding (PE) of skip size N reduces filed-of-view by a factor of N, leading to aliasing ghosts in PE direction with up to N layers of overlapping (assuming no aliasing without skip). In parallel imaging, at least N ghosted images are acquired with multiple RF coils, and a deghosted image is estimated from an over-determined linear system. SPEED acquires a set of M similarly ghosted images, and achieves deghosting using edge maps, reducing the scan time by a factor of M/N with M < N. The M images are acquired by shifting the PE by d steps, with M different d values chosen from $0,1,...N-1$, resulting in a ghost phase rotation of $P_d^{\,n}$, where P_d is a known phasor given by $P_d = \exp(i2\pi d / N)$ and $n = 0,1,...N-1$ is the order of ghost depending on its location. For ordinary images, N such images are needed to resolve all possible N overlapping ghosts at an arbitrary pixel. However, the number of overlapping layers can be significantly reduced if edge maps are considered. After a gradient operation, or a corresponding k-space high-pass filtering, ghost overlapping of up to only 2 dominating layers at each pixel is seen to adequately model most practical images. These 2 layers of ghosts can be resolved with 3 equations shown below, obtained with only M=3 shifted acquisitions.

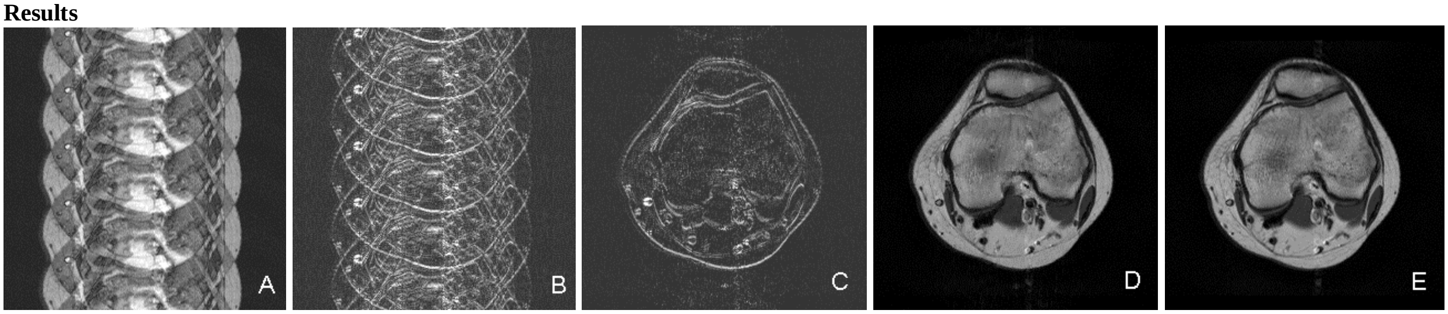
$$I_1 = P_1^{n1} G_1 + P_1^{n2} G_2 \qquad (1)$$

$$I_2 = P_2^{n1} G_1 + P_2^{n2} G_2 \qquad (2)$$

$$I_3 = P_3^{n1} G_1 + P_3^{n2} G_2 \qquad (3)$$

As long as N is a prime number, equations (1-3) can be solved by minimizing the least-square-error (LSE) through trials of limited number of possible values of n1 and n2 at each pixel. After N sets of such ghosts are obtained, they are spatially registered and averaged as a deghosted edge map with improved SNR. Finally, the deghosted edge map is integrated or inverse filtered to produce the desired deghosted image. Slightly more scan time can be spent efficiently to acquire few (*e.g.* 32 out of 256) central k-space lines to avoid dividing by small numbers in the inverse filtering. SPEED has been successfully tested with *in vivo* data and is demonstrated below with a spin-echo transverse knee scan.

Results



A is one of the 3 ghosted images with PE skip size N=5, having up to 5 layers of ghost overlapping. B is the corresponding edge map after high-pass filtering, with ghost overlapping layers reduced to be mostly only 2. C is the edge map after degosting by a LSE solution of equations (1-3). D is the final deghosted image after inverse filtering of C, as compared to the gold-standard E with full k-space sampling. All images were actually complex but are shown here in magnitude only for easy visualization. The result is of reasonable quality although the scan time has been reduced by a factor of nearly 3/5=0.6.

Discussion

The high-pass filtering in SPEED effectively reduces ghost overlapping layers, allowing a straightforward LSE solution of individual ghosts. The final image is reconstructed by an inverse filtering of the deghosted edge map. SPEED uses the fact that most practical images have sparse edge maps with much less chance of ghost overlapping. In case the image is very rich in edges, more than 3 acquisitions may be needed to resolve more than 2 ghost layers as indicated by the residual in the LSE solution. In the extreme case, SPEED can naturally merge into ordinary acquisition and reconstruction. Therefore, SPEED is an efficient method specifically tailored to the image content and is able to compress scan time whenever possible. As an independent method, SPEED can also be combined with parallel imaging methods for improved performance.

References

[1] DK Sodickson and WJ Manning, MRM, 38, 591-603, 1997
[2] KP Pruessmann, *et al*, MRM, 42, 953-962, 1999