Pulsatile Motion Suppression using Cine Fast Spin Echo and Non-Linear Image Reconstruction

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Target audience: This research will be of interest to those aiming to remove motion artifacts and improve image resolution.

Purpose: High resolution MR imaging is now limited by physiological noise and motion rather than raw signal or thermal noise. While much work has been devoted to correcting bulk motion, the effects of brain pulsation (which present as periodic non-affine deformations) have largely been ignored. Portions of the brain displace by as much as 0.5 mm with the cardiac cycle [1] — this motion imposes a fundamental limitation to the resolution that can be achieved in these regions with standard imaging techniques. Even when the image resolution is larger than 0.5 mm, blurring and ringing artifacts are common. Prospectively gated sequences avoid pulsatile motion; however, scans are often prohibitively long. We propose a retrospectively gated FSE sequence [2] combined with an advanced dynamic sparseSENSE image reconstruction to identify and suppress pulsatile behaviour. Our proposed method enables high-resolution brain imaging and is insensitive to non-rigid pulsatile motion that was previously uncorrectable.

Methods: All data was acquired on a 3T GE MR750 scanner. Pulse-oximeter data was recorded concurrent with image acquisition to enable retrospective gating. Standard parameters were: TR/TE of 2750 ms/45.5 ms, FOV of 220 x 220 mm^2, acquisition matrix of 512 x 504, and slice thickness of 3 mm. A modified FSE sequence was designed to pseudo-randomly sample k-space lines (while preserving image contrast and point spread function). Low-frequency k-space data was oversampled to ensure full coverage of the centre of k-space in each cardiac phase. This data was reconstructed into two image sets. A static image was obtained by temporally averaging and density correcting all data (called "*variable density FSE*"). Dynamic images were obtained by retrospectively binning k-space data into 12 evenly spaced cardiac phases. Each cardiac phase, now a randomly undersampled k-space, was reconstructed from a temporally constrained sparseSENSE image model [3]:

$$\arg\min_{\mathbf{m}}\left\{\|\mathbf{FSm}-\mathbf{y}\|_2^2 + \lambda_1\|\mathbf{\Psi m}\|_1 + \lambda_2\|\bar{\mathbf{m}}-\mathbf{m}\|_1 + \lambda_3\mathbf{TVm}\right\}$$

where $\mathbf{F}$ is a 2D Fourier transform undersampling operator, $\mathbf{S}$ is the coil sensitivity encoding matrix, Ψ is the wavelet transform matrix, $\bar{\mathbf{m}}$ is a temporally-averaged fully-sampled image (the variable density FSE image) and $\mathbf{TV}$ acts as a temporal high-pass filter. The weighting factors, λ_1, λ_2 and λ_3 are set independently for each constraint term. The dynamic image series was used to generate a temporal variance map. A high quality static image (called "*motion corrected FSE*") was formed by temporally averaging across the cardiac phases, while excluding pixels/phases that experience corruptive motion, as identified on the variance map.

Results: Standard FSE images (Fig 1a,b) of a healthy cooperative volunteer show blurring (red arrow) and ringing (yellow arrow) due mainly to pulsatile motion. Improved image quality is seen with the proposed variable density FSE (Fig 1c). Increased detail near the edge of the brain and near arterial structures is evident and motion induced ringing is nearly completely suppressed. The dynamic image set successfully identified pixels that are prone to pulsatile motion (Fig 1e); exclusion of pulsatile phases in these pixels from dynamic averaging results in a static image that is extremely insensitive to pulsatile motion (Fig 1d). Overall, increased homogeneity in the cortex is observed and sharper vascular structures are seen with our proposed methods relative to standard FSE.
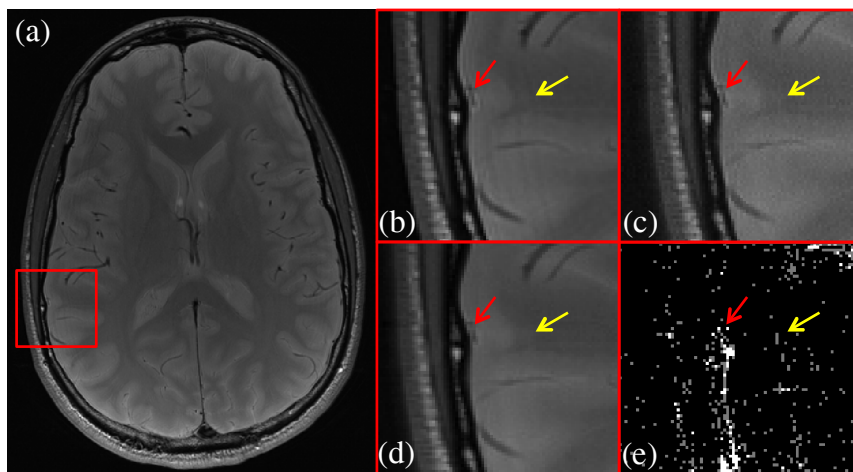

Fig. 1 (a) One slice from a standard whole-brain FSE scan. (b) Zoomed uniform-density FSE (i.e., vendor standard), (c) variable-density FSE, (d) motion corrected FSE, obtained by averaging dynamic images after removal of motion corrupted pixels/phases identified in the (e) temporal variance map. Reduced ringing (red arrow) and increased resolution near the cortex and vascular structures (yellow arrow) are observed.

Discussion: Relative to standard sampling, variable-density FSE provided a significant reduction in motion artifacts. This is due to (a) oversampling the centre of k-space [4], and (b) randomizing the sampling order. With this approach, pulsatile motion is incoherently distributed throughout k-space. This sampling scheme is also amenable to an advanced dynamic reconstruction; regions with significant cardiac motion can be identified (Fig 1e) and removed to produce a motion corrected FSE image (Fig 1d). Further optimization of the reconstruction constraints and regularization terms in Eq. [1] are anticipated to improve the contrast and spatial resolution of the motion corrected FSE image.

Conclusion: FSE with random and variable density sampling is advantageous for pulsatile motion suppression and enables several reconstruction pathways. Direct reconstruction of the variable density FSE is simple, fast, and produces high quality images, despite incorporating motion-corrupted data. Advanced reconstruction with parallel imaging and sparsity constraints can identify and remove this inconsistent data to produce an even cleaner image. Our proposed method has the potential to drastically improve the quality of clinical FSE imaging without requiring additional scan time.

References

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