Efficient Large Scale Motion Compensation for Multi-Shot Diffusion-Weighted Imaging

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Purpose: Although multi-shot sequence has been widely used to achieve high spatial resolution diffusion-weighted MR imaging, artifact issue due to inter-shot motion has not been well resolved. MUSE [1] and IRIS [2] were recently proposed to correct phase errors induced by the sub-voxel motion in multi-shot EPI imaging. However, they both assumed that there is no large scale inter-shot motion (i.e. larger than 1 pixel). The assumption cannot be always met in clinic because of patients' involuntary movement. The goal of this work is to provide a novel method for multi-shot acquisition, which can robustly deliver high quality image even when there is large scale inter-shot motion.

Methods: This work is based on MUSE, which takes advantage of the strong correlation among the shots that the multi-shot images share the same magnitude if there is no large scale motion. The key idea is to first classify the shots into clusters which assumedly have no large scale intra-cluster motion. Hence, each cluster can use MUSE to obtain an intermediate image. After that, these intermediate images are registered to correct the inter-cluster motion and combined to generate the final reconstruction. Fig.1 shows the flowchart of the proposed method. First, individual image of each shot is generated with SENSE [3]. Second, the dissimilarity based on the correlation among images is calculated, and hence the images are clustered accordingly. Third, each cluster is reconstructed by MUSE. Then, the intermediate images are registered to the referenced image which is reconstructed from the largest cluster. Finally, the weighted average of these registered images is used as the ultimate reconstruction. If there is no large scale inter-shot motion, the method is degraded to MUSE. If there is large scale inter-shot motion, our method can remove the effect of motion by clustering and registration. This method combines clustering with MUSE, and thus is named as clustered MUSE (cMUSE). Besides ms-EPI, this scheme can also be adopted to improve other multi-shot imaging scheme, such as multi-shot TSE.

To assess the performance of cMUSE, a multi-shot EPI brain data set and a multi-shot TSE abdominal data set were acquired on a Philips 3T Achieva system (Philips healthcare, Best, the Netherlands). The acquisition parameters for the brain data set include: number of signal averages (NSA) = 4, number of shots (NS) = 4, number of coils (NC) = 8. To simulate the motion, we rotate (9° and 12°) and translate (2 pixels along the two directions in plane) the image reconstructed with the brain data, and the corresponding data in k-space are used as the data of the 3th and 4th shot respectively. The acquisition parameters for the abdominal data set include: NSA= 1, NS = 4, NC = 32.

Results: Fig. 2 shows the comparison of the reconstruction with SENSE average, MUSE and cMUSE on the brain dataset. The MUSE reconstruction (Fig.2b) contains significant artifacts due to large scale inter-shot motion. In contrast, no obvious artifacts can be observed in the image reconstructed by cMUSE (Fig.2c). The enlarged views (Fig.2d and Fig.2e) show that cMUSE can achieve higher SNR and suppress artifacts compared with SENSE average, which is the average of the SENSE reconstruction of each shot after registration. Fig. 3 compares the reconstruction with MUSE and cMUSE on the abdominal data set. It can be seen from the enlarged views that the artifacts in MUSE reconstruction are significantly suppressed by cMUSE.

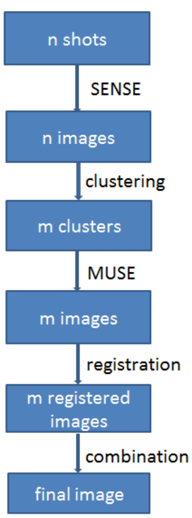

Fig.1 Flow diagram of cMUSE. n shots and m clusters are assumed.

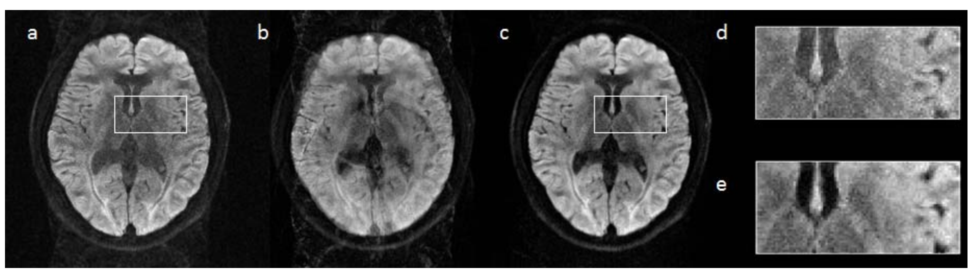

Fig. 2. Reconstructions of the 4-shot brain data set (NSA=4). (a) SENSE average, (b) MUSE, (c) cMUSE. (d) and (e) are enlarged parts in (a) and (c), respectively.

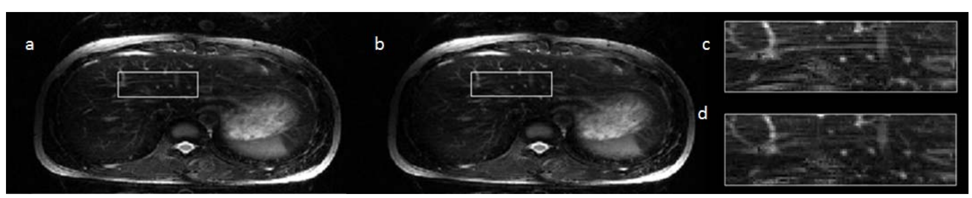

Fig. 3. Reconstructions of the 4-shot abdominal data set sequence. (a) MUSE, (b) cMUSE. (c) and (d) are enlarged parts in (a) and (b), respectively.

Discussion: MUSE [1] and IRIS [2] cleverly use the strong inter-shot correlation that all the shots share the same magnitude, and can produce images with higher SNR compared with conventional SENSE [3]. However, they achieve high image quality on the condition that there is no large scale inter-scan motion. In this work, we extend MUSE to address the issues related to shot-to-shot large-scale motion. The proposed method groups shots into clusters, reconstructs each cluster with MUSE by taking advantage of the same magnitude property inside each cluster, and corrects the inter-shot motion by image registration techniques. We expect to improve the SNR by combining the iterative motion compensated reconstruction [4] in the future.

Conclusion: The large scale motion issue in multi-shot imaging can be solved by clustering before the MUSE reconstruction and registration after reconstruction.

References: [1] Chen, N-k, et. al. NeuroImage 2013;72:41-47 [2] Jeong, H-k., et. al. MRM 2013; 69:793-802 [3] Pruessmann K.P., et. al. MRM 1999;42:952-962. [4] Nielsen, T., et.al. MRM 2011;6:1339-1345.