Artifact correction based on diffusion coefficient

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Target Audience MR scientists/clinicians interested in accurate estimation of DTI metrics

Purpose The systematic vibration artifact (SVA) is a localized region of signal dropout (Fig. a) observed in diffusion weighted imaging (DWI) [1]. In our case of a 3T wide-bore Siemens Tim-Trio system, the SVA occurs in up to 10% of acquired DWI images and does not show a direct preference along any particular diffusion direction, in contrast to Ref [1] which studied SVA exclusively in brain. SVA is more prevalent in body imaging, as it is sensitive to vibration that would have been attenuated in brain imaging. To remove SVA one can use either generalized image processing techniques such as outlier detection or histogram based methods, or advanced outlier detection techniques combined with robust estimation, such as RESTORE and iRESTORE [2, 3]. Though effective, these methods encounter problems with small acquisition sets, which are not uncommon in clinical settings. Our method, which we refer to as Artifact Correction based on Diffusion Coefficient (ACDC), requires either multiple average or multiple directions and is effective even with one direction. ACDC is, essentially, a rejection scheme based on unphysical diffusion coefficient values of the directional apparent diffusion coefficient (ADC).

Methods ACDC was applied on a DWI data set acquired of the right calf muscle using a unilateral 15-channel knee coil. DWI images were acquired along 20 gradient directions for $b = 0$ and $0.5\ \mu m^2/ms$, using a stimulated echo diffusion preparation. Other imaging parameters were: 1 average, TR = 7.4s, TE = 42ms, matrix = 64×64, thickness = 10 mm, and TD = 57ms. Total scan time was 2 minutes.

The artifact is encountered only in the presence of diffusion weighting, as it is absent when the gradient field is turned off, $b = 0$. Considering this, it is prudent to examine signal intensities of a directional ADC map (dADC) for any direction α taken from the b-matrix: $dADC_\alpha = (-1/b_\alpha)\ln(S_b^\alpha/S_0)$ where b_α is the b-value in direction α. Signal dropout in S_b^α should result in large values in the $dADC_\alpha$ map (Fig. b). As the highest naturally occurring diffusion coefficient in water is $3.0\ \mu m^2/ms$, any greater ADC-value is a predictor for the presence of the SVA. This physical value should serve as an upper limit for thresholding. During pseudo inversion for determination of the eigenvalue maps, artifactual directions are excluded. The actual threshold was determined through an iterative histogramming method, whereby a spectrum of possible ADC thresholds $\leq 3.0\ \mu m^2/ms$ is applied. A threshold of $2.4\ \mu m^2/ms$ was used for this dataset.

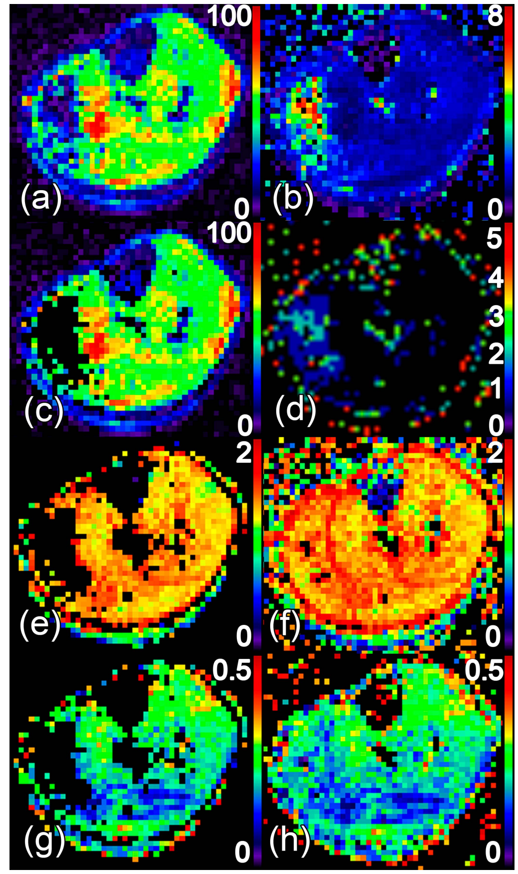

Figure: (a) Calf muscle DWI intensity at b=500 in B_{yz} direction; (b) Directional ADC (dADC) in $\mu m^2/ms$; (c) Filtered Artifact, $dADC < 2.4\ \mu m^2/ms$ and converted back into DWI; (d) The number of removed voxels across 20 directions; Eigenvalue map across λ_2 before (e) and after ACDC (f); Fractional Anisotropy before (g) and after ACDC (h);

Results From the artifact map (Fig. d), it is evident that the large region of signal dropout affecting responsible for damaged ADC and FA maps (Fig e, g) was the result of one faulty diffusion direction. Despite the invasiveness of the SVA, ACDC is fully capable of capable of artifact removal. Image reconstruction following pseudo-inversion yields an image that appears unaffected by the SVA. The SVA does not appear more frequently in any particular direction. Based on our experience on 3T and 7T scanners, the artifact's pervasiveness seems to be dependent on the individual scanners.

Discussion In the search for a better artifact removal procedure, several image processing methods were attempted, but had to be abandoned. Datasets were far too small to rely on outlier detection, since artifact voxels would often be preserved while non-artifactual voxels would be discarded. Applying histogram thresholding based on image intensity is particularly difficult due to RF inhomogeneity. Instead, using ACDC is equivalent to normalization on the $b = 0$ image, which makes our approach insensitive to field inhomogeneities. Our proposed method, ACDC, is preferable as it exploits physical interpretation of diffusion, resulting in a robust nonlinear model for artifact filtration in DWI.

Conclusion ACDC is a method of artifact removal that eliminates individual voxels of corrupted diffusion directions. As long as the number of remaining directions is ≥ 6, the full diffusion tensor can still be obtained. Therefore, oversampling by acquiring more directions is superior and more time efficient than acquiring more averages. ACDC is most practical when applied to a clinical setting. In contrast to outlier detection, ACDC does not require many directions or averages to be efficient and its implementation in clinical systems would be straightforward.

References [1] Gallichan et al. Hum. Brain Mapp. **31**:193, 2010; [2] Chang et al. Magn. Reson. Med. **53**:1088, 2005; [3] Chang et al. Magn. Reson. Med. **68**:1654, 2012;