Acquisition strategies for highly accelerated Diffusion weighted imaging

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Target audience: Researchers interested in diffusion MRI and acquisition of such data.

Purpose: Diffusion Weighted Magnetic Resonance imaging (DW-MRI) provides the microstructural data of human brain. However, the acquisition of multiple *b* values for computation of Apparent Diffusion Coefficient (ADC) and Diffusion Tensor Imaging (DTI) maps are time consuming. There are several methods to reduce the scan time such as optimal gradient design, parallel imaging and pulse sequence optimization techniques. The significant points on k-space depend on the structure of the organ and are typically arbitrary. A method that combines the usage of active contours and convex optimization for the design of optimal gradient waveforms for arbitrary k-space trajectory is being proposed for DWI. ***Theory:*** The active contour [1] is an energy minimization technique represented by $E_{snake} = \int_0^1 E_{int}(\boldsymbol{V}(s)) + E_{image}(\boldsymbol{V}(s)) + E_{con}(\boldsymbol{V}(s))\, ds$ where $E_{int}(\boldsymbol{V}(s))$ is the internal energy of the spline due to bending, $E_{image}(\boldsymbol{V}(s))$ is the image forces and $E_{con}(\boldsymbol{V}(s))$ is the external constraint force.A k-space mask consisting of the significant points can be used as an image. By selecting a seed point which encompasses the significant region, the active contour can be made to shrink from the boundary to its center resulting in a tweaked spiral like arbitrary k-space trajectory. An optimization tool such as convex optimization (cvx) [2] can be used for the design of optimal gradient waveforms by solving for $\|k - A \times g\|$ under hardware limiting constraints such as maximum gradient amplitude, maximum slew rate etc. Here $\|.\|$ represents the norm, *k* represents the k-space trajectory at time *t*, *A* represents the integration matrix and *g* represents the gradient amplitude at time *t*. The integration matrix is developed based on the trapezoidal rule. ***Methods:*** The k-space data was acquired on a 1.5T clinical scanner (Magnetom Avanto, Siemens) for six healthy volunteers with the following parameters for the Spin-Echo based EPI sequence TR/TE = 3000/104 ms, resolution = 128 × 128 mm^2, with *b* values = 0, 200, 400, 600, 800, 1000, 2000 s/mm^{2}and with six diffusion directions. For each data set, the k-space was undersampled for the acceleration factors: 3x, 4x, 5x, 10x and respective k-space masks were generated. Morphological operations of erosion and dilation were performed within a loop thereby maintaining the percentage undersampling of the mask within ±2% tolerance. The active contour technique was used to move throughout the significant points on the mask, from the boundary to the center, resulting in an arbitrary shaped tweaked spiral like k-space trajectory. The k-space trajectory was verified to reproduce the input k-space mask. Fourier transform was applied on the product of the verification mask and original image intensity to obtain the reconstructed image. The number of points on the k-space trajectory was subsampled so as to match the computational efficiency of the computer (specifications: Intel core i3, 2.40 GHz, 4 GB RAM). The gradient waveforms were generated for the subsampled k-space trajectory by using cvx and subjecting the gradient variable to maximum gradient amplitude constraint Gmax = 50 mT/m and maximum slew rate constraint SRmax = 100 T/m/s. The total time duration for the computation was approximately two minutes. Verification for the attained gradients was performed by obtaining the k-space trajectory by solving gradient to k-space trajectory equation analytically. The ADC maps were obtained for both the original image and the image obtained after active contour for *b*=0, 200, 400, 600, 800, 1000 and 2000. Difference images were obtained by subtracting reconstructed image from the original image. ***Results:*** Figure 1(a) shows the image for full k-space with $b = 200\ \mathrm{s/mm^2}$. Figure 1(b) shows the undersampled (33%) k-space mask. The red curve indicates the region enclosed after morphological operations. The blue dots represent the subsampled k-space trajectory obtained from active contour. The green dots represent the verified k-space trajectory obtained from the cvx optimized gradient waveforms analytically. Figure 2(a) represents the gradient waveforms as solved by cvx optimization. Figure 3(a) Shows ADC maps generated from original DW images for 3x, 4x, 5x and 10x acceleration factors. Figure 3(b) Shows image reconstructed after the application of active contour for 3x, 4x, 5x and 10x acceleration factors. Figure 3(c) shows the difference image between reconstructed ADC image and original ADC map image. ***Discussion and conclusion:*** The combination of active contour and cvx for dynamic scans such as DWI has been established for the first time. It can be observed from the figure 3 that the proposed method performs well when introducing various acceleration factors. The technique can be implemented for arbitrary k-space trajectories and hence provides a general framework. Current and future work involves optimizing k-space trajectories to suit specific ROI shapes and implementation of this technique to DTI [3] to compute Fractional Anisotropy (FA) maps and integrating it on 1.5 T Optima, GE, thereby reducing scan time during acquisition.

Reference: [1] M. Kass et al. International Journal of Computer Vision, 1988. [2] M. Grant and S. Boyd disciplined convex programming. [3] Jiang Y et al. MRM, 2005

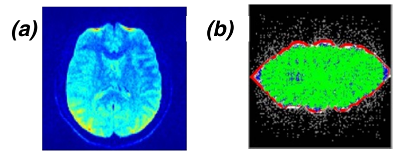

Figure 1: (a) Image from full k-space with b=200 s/mm^2. (b) Undersampled k-space mask, Morphological operated mask (red curve enclosure), subsampled k-space trajectory points from active contour (blue dots). Verified k-space points from designed gradients (green dots).

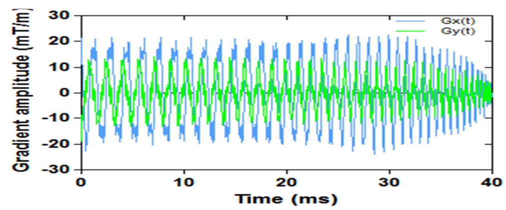

Figure 2: Gradient waveforms for DWI image with b = 200 for 33 percent undersampling.

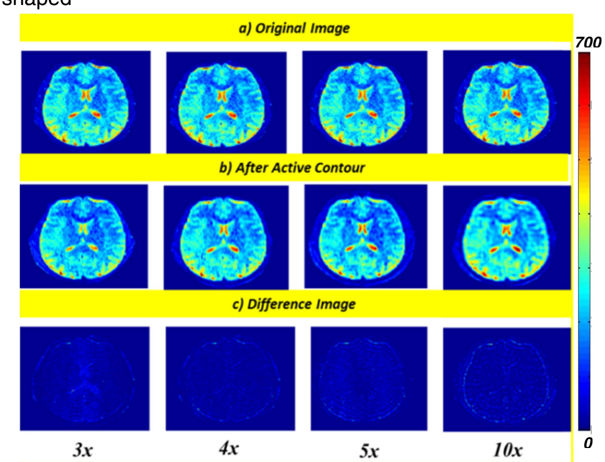

Figure 3: (a) ADC maps of original DW images, (b) ADC maps after reconstruction and (c) Difference image map between original and active contour ADC map.