Acquisition strategy for limited support Compressed Sensing

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Target audience: Researchers interested in accelerated acquisition/reconstruction of dynamic MRI.

Purpose: Dynamic MRI methods such as cardiac MRI require fast acquisition of data for increased temporal resolution to avoid artifacts and image the functions. The Region of Interest (ROI) is typically smaller compared to the entire image and the Field of View (FOV) cannot be reduced beyond a certain extent to view the ROI distinctly. The ROI selected image data will be sparse and will provide for better image reconstruction using Compressed Sensing (CS) [1] method. The shape of the significant values of k-space depends on the structure of the ROI and is typically arbitrary. A method that combines the usage of active contours and convex optimization for the design of gradient waveforms for the arbitrary k-space trajectory is being proposed based on the work of ref [2] where in ROI based CS reconstruction has been demonstrated.

Theory: The active contour model [3] is a framework that attempts to minimize the energy associated with the current contour as a sum of the internal and external energy. It is represented by $E_{snake} = \int_0^1 E_{int}\big(\boldsymbol{V}(s)\big) + E_{image}\big(\boldsymbol{V}(s)\big) + E_{con}\big(\boldsymbol{V}(s)\big)\, ds$, where $E_{int}\big(\boldsymbol{V}(s)\big)$ is the internal energy of the spline due to bending, $E_{image}\big(\boldsymbol{V}(s)\big)$ is the image forces and $E_{con}\big(\boldsymbol{V}(s)\big)$ is the external constraint force. An undersampled mask of a given k-space can be used as an image and since active contour moves like a snake it can be used to obtain tweaked spirals of arbitrary shapes to traverse this k-space. The relationship between the k-space trajectory and gradients is given by $k(t) = \frac{\gamma}{2\pi}\int_0^T g(t)dt$ [4], where *k(t)* is the k-space trajectory at time *t* (mm^{-1}), $\frac{\gamma}{2\pi}$ is the gyromagnetic ratio (42.56 MHz/T), *g(t)* is the gradient amplitude at time *t.* The convex optimization (cvx) [5] can be used to solve the inverse problem of obtaining gradient waveforms from the k-space trajectory given by the active contour by solving for $\|(k - Ag)\|_2$, subjected to maximum gradient amplitude and maximum slew rate. Here$\|.\|$ represents the norm,k is the k-space trajectory from active contour, A is the integration matrix and g is the gradient waveform. The integration matrix is developed based on the trapezoidal rule where a given waveform is segmented into trapezoids of equal width Δt. The area under each segment is evaluated and summed together to obtain the area under the curve. ***Methods:*** The experiments were performed on cardiac MRI data acquired from ten human volunteers as part of an Institutional Review Board (IRB) approved MRI study. 2D Multi-slab cardiac datasets were acquired on 1.5T scanner (Signa HDxt, GE) with TR/TE=5.09/1.42 ms, matrix size=256×256 with slice thickness of 8 mm using contrast agent Magnevist. ROI was selected in cardiac image by considering the short axis view since the remaining part of the image was not required for further analysis as shown in figure 1(a). The k-space was obtained for the ROI selected image was then undersampled at chosen acceleration factors (3x, 4x, 5x and 10x). Morphological operations of erosion and dilation were performed such that a defined region of significant k-space was obtained separating it from the background. The processed mask was given to the active contour and an arbitrary k-space trajectory was obtained. A mask was generated from the k-space trajectory and the image was reconstructed by Fourier transform. The k-space trajectory was subsampled to reduce the number of points in order to match the computational efficiency of the computer (specifications: Intel core i3, 2.40 GHz, 4 GB RAM). The total time for computation was approximately two minutes. The gradient waveforms were designed by cvx under maximum gradient amplitude constraint (Gmax=50 mT/m) and maximum slew rate constraint (SRmax=100 T/m/s). The obtained gradient waveforms were verified by integrating them analytically and comparing with the subsampled k-space trajectory. ***Results:*** Figure 1(a) shows a cardiac frame with a chosen ROI. Figure 1(b) shows the undersampled (10%) 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 optimized gradients analytically. Figure 2 represents the gradient waveforms as solved by the cvx. Figure 3(a) shows the ROI images at chosen acceleration factors 3x, 4x, 5x and 10x. Figure 3(b) shows the image reconstructed after active contour. Figure 3(c) shows the difference between reconstructed image after active contour and original image. The quality of reconstruction can be varied by the difference image which shows that there is no significant difference between original and reconstructed image. Figure 4 shows the Normalized Root Mean Squared Error (NRMSE) for different acceleration. ***Discussion and conclusion:*** ROI based image acqusition and reconstruction using active contour model has been performed retrospectively for the first time. Instead of looking at k-space specific to ROI, locations in k-space that are highly relevant to that ROI are arbitrary shaped and a reconstruction framework for such acqusitions exists (ROICS). The designed gradient waveforms are observed to meet the specified constraints, additional constraints such as Pheripheral Nerve Stimulation (PNS) etc are allowed within the framework. The error lies in the same range and can be observed that the standard deviations of the four acceleration overlap with each other and hence the error is noted to be consistant over these accelerations.

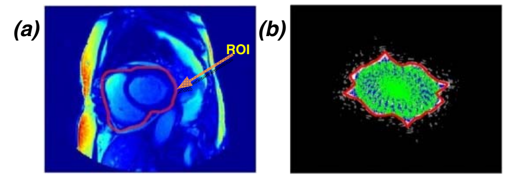

Figure 1 (a) A cardiac frame with a chosen ROI in red (b) Undersampled k-space mask of the ROI, mask after morphological operation (red curve), subsampled k-space trajectory points (blue dots). Verified k-space points from designed gradients (green dots).

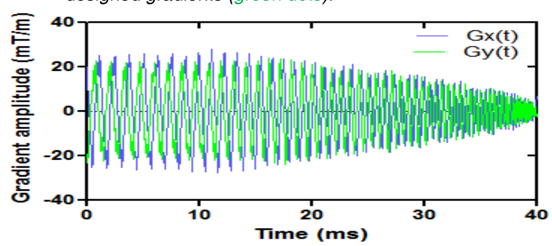

Figure 2: Gradient waveforms obtained for 10x acceleration factor

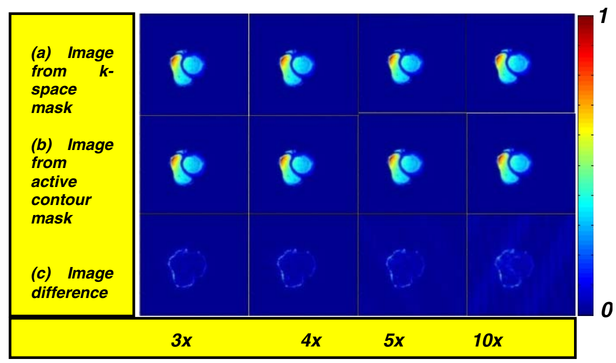

Figure 3: An image of the ROI chosen from cardiac data.

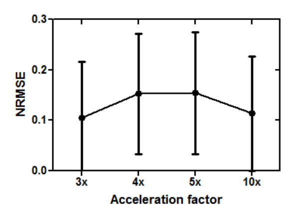

Figure 4: NRMSE for different accelerations

References: [1] M. Lusting et al., MRM, 2007. [2] A. S. Konar et al., Journal of Indian Institute of Science, 2014. [3] M. Kass et al., International Journal of computer vision, 1988. [4] Hand book of MRI Pulse Sequences, Matt. A. Bernstein. [5] M. Grant and S. Boyd, Disciplined convex programming, 2014.