Spatio-Temporal Bandwidth-Based Segmented Acquisition for Dynamic 3D Contrast-Enhanced Breast MRI

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Introduction

Dynamic contrast enhanced (DCE-MRI) of the breast should ideally be performed at high temporal and high spatial resolution to evaluate both enhancement dynamics and lesion spatial-architectural features (1,2). There is, however, an inherent tradeoff between the maximum achievable temporal and spatial resolution (3). In this work, a formalism is presented that considers the dual bandwidth properties of an object's spatial and temporal enhancement features, in devising a segmented k-space 3D (N_x readout, N_y N_z phase encode) acquisition scheme.

Methods

In this formalism, the slowest phase-encoding axis, say k_y, is chosen as the axis along which k-space traversal will be traded for increased temporal sampling. Therefore, in the initial analysis a simple 1-D temporally modulated object is considered. Let M(y) represent the object spatial features which are separable from the temporal features given by C(t), simulated to show breast lesion-like enhancement using a pharmacokinetic model (4), (Fig 1.). The sampling bandwidth criteria will be determined by analyzing the "k_y - k_t" Fourier domain of this composite spatio-temporal object (Fig 2.). For a given TR, rate of digitization along k_y is given by, $Rk_y = 1/(TR{*}N_z)$. If $Tmax$ is the overall imaging duration, then maximum number of k_y samples that can be acquired is, $Nmax = Tmax \cdot Rk_y$. Correspondingly, maximum allowable bandwidths are: $k_{ymax} = 1/Nmax$; $k_{tmax} = 1/Tmax$. The 2-D k_y - k_t spectral map ($Nmax$ x $Nmax$) is generated, by taking the outer product of the Fourier transforms ($FT(M(y))' \times FT(C(t))$ at maximum bandwidth. The optimization criterion for trading off spatial and temporal bandwidths from this dual spectral map is

$$MAX\left[\sum_{1}^{Nky}\sum_{1}^{Nkt}\hat{M}(ky)\cdot\hat{C}(kt)\right], \text{ such that } Nky \times Nkt \leq N\text{max} \quad [1]$$

where, $\hat{M}(ky)\cdot\hat{C}(kt)$ is the instantaneous spectral power in the enhancement modulated object. This yields an area plot within the "k_y - k_t" domain that contains the greatest spectral power for the given spatio-temporal object, constrained by Nmax samples. For any given spatial bandwidth included in this area, the corresponding temporal sampling bandwidth can be determined.

This analysis is extended over a selected range of simulated object size and enhancement conditions. Simulations are based on a 3D SPGR sequence with parameters TR = 10ms, TE = 4.6 ms , flip = 40°, matrix = (256x128x32), $Tmax$ = 3'20'', $Nmax$ = 640, object dia: 1-40mm, enhancement rate: rapid (k = 0.05-s) , medium(k= 0.003-s) and slow (k = 0.0013-s) (4). Over all of the resulting area plots, a histogram of the maximum and mean k_t bandwidths for discrete segments of k_y is obtained. These are used as guidelines to design the segmented acquisition.

Results and Discussion

A histogram of the resulting temporal bandwidth requirement for 8-line bins in k_y is shown in Figure 3. From these results the recommended acquisition would be to sample the central 16 k_y lines at 11-15 temporal samples, the next 16 at 9-13 temporal samples and so on. The k_y- k_t analysis suggests that k-space traversal should be tailored such that central segments of k_y are sampled at a high rate and peripheral segments are sampled at a progressively slower rate. This formalism provides an objective method to design and rank acquisition strategies that address the spatial and temporal resolution tradeoff in DCE-MRI.

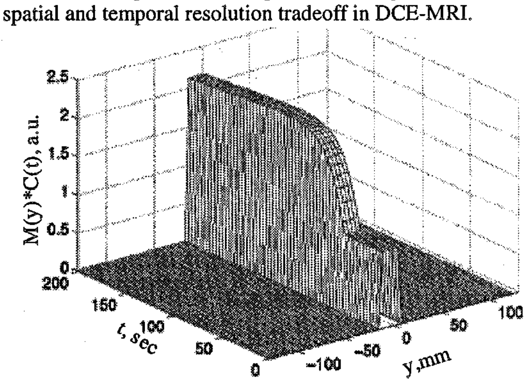

Fig1: Example of combined spatio-temporal object . M(y)*C(t) is instantaneous contrast modulated spatial object intensity.

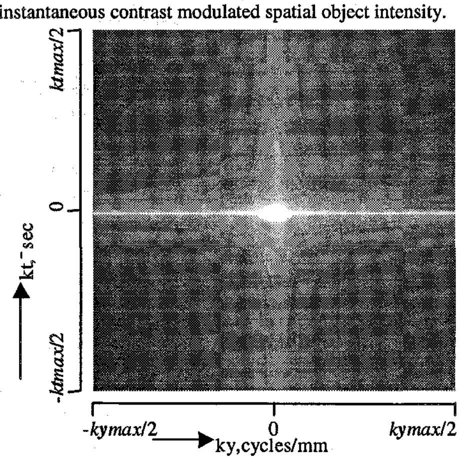

Fig2: Fourier "ky-kt" domain representation of spectral power in given spatio-temporal object. Sampling strategy based on maximization of power contained in Nmax samples.

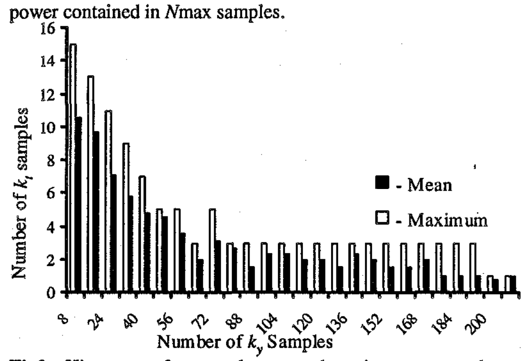

Fig3: Histogram of temporal mean and maximum temporal sampling constraints for discrete segments in k_y space, over range of spatio-temporal objects.

References

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