Implementation of Hybrid Basis Non-Fourier Spatial Encoding for Dynamic Adaptive MRI

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Introduction

Hybrid basis non-Fourier spatial encoding (HBSE) (1) is a generalization of the digital wavelet concept (2), to modify efficiently-encoding basis sets, e.g., wavelets or linear algebra-derived spatial encodes used in dynamically adaptive MRI. Approaches for HBSE can be designed in part based on rank revealing numerical linear algebraic methods as used previously in our laboratory for dynamically adaptive MRI (3-5). Dynamically adaptive MRI exploits algorithms, sophisticated mathematics and computer power for dynamically adapting data acquisition to take advantage of a priori known information and new information available during a dynamic MRI series to increase acquisition efficiency and enhance image quality. The particular focus here is on adaptive (on-the-fly) computed spatial encodings, derived mathematically from the estimated contents of the FOV, and reliant upon use of spatially selective radio-frequency (RF) excitations for implementation. With near-optimal encoding efficiency, HBSE aims for digital RF waveforms providing: more accurate excitation by digital RF transmitters, reduced tissue RF power deposition, and increased image signal-to-noise (SNR).

Hybrid Basis Spatial Encoding

The first category of HBSE approaches uses encodes that are l.c. of computed near-optimal basis vectors from a rank revealing orthogonal decomposition (RROD), $S = QR$, of an estimate, $S$, of the ideal k-space data array to be acquired. $Q$ is a minimal set of basis vectors spanning the column space of $S$, i.e. vertical spatial encoding. Even if $S$ has large dimensions (e.g., $256^2$) its rank can be low (e.g., $30-50$) so relatively few vectors ($|q_i|$) forming $Q$ are needed for exact complete encoding. If $W$ is a column matrix of vectors representing coefficients of l.c. of $|q_i|$, then HBSE is $Q_{hybrid} = WQ = (W^tW)^{-1}(W^t)$ (where $A^* = (A^*)^t$).

A second category of approaches uses l.c. of a (known or ad hoc) basis with desirable physics properties where specific l.c. are determined from computed $|q_i|$ as $Q_{hybrid} = WQ = (W^tW)^{-1}(W^t)$. Advantageously, features of near-optimal encoding can be incorporated with encodes having favorable MR point-spread-functions (PSF) (2). Many HBSE variations are possible (1).

Methods

Images were acquired from a grapefruit phantom using a low flip angle ($\leq 30$ deg) gradient-recalled echo (GRE) pulse sequence (TE 10ms TR 1000ms; FOV 16cm, 8 vertical encodes; 128 frequency encoding points reconstructed to 128x128) on a 1.5T GE SIGNA LX MR scanner employing in-plane non-Fourier spatially selective RF excitation and no slice selection. Standard phase encoded GRE results and SVD encoded MRI results (3) were acquired for comparison purposes.

Results

Several variants of HBSE approaches have been implemented. One example (Fig. 1 top left) of the first HBSE approach, uses Gaussian weighted l.c. of the Walsh-Hadamard l.c. of a set of $Q$ near-optimal vertical-encoding vectors from the SVD of the image estimate (a previous image in a series) to form encodings, $Q_{hybrid}=QW$. Motivation for $QW$ use involves averaging power deposition over RF excitations and forming RF waveforms leading to higher SNR and lower artifact images. If $S'$ represents the k-space of FOV contents, acquired data is $S_{acq}=Q_{hybrid}S'$.

Fig. 1 top right shows experimental results of one variant of the second general HBSE approach. HBSE were determined as Gaussian convolved vertical SVD encodes (4) similar to approach of digital wavelets (2). Encoding benefits here are derived from closer correspondence with the MR point spread function, providing possibilities for greater SNR and contrast-to-noise ratio.

Fig. 2 is a demonstration of HBSE 'free-form' RF waveform encoding using 64 Gaussian-shaped waveforms for vertical encoding, from which near-optimal encoding can be derived posteriori in post-processing of samples (1).

Conclusion

We described and demonstrated experimental results of two general mathematical approaches for HBSE, designed to allow greater freedom in designing spatially selective RF excitations for dynamically adaptive MRI. This implementation and systematic theory of HBSE provides a framework for understanding the designs of 'free-form' spatial encoding and encodes tailored for better PSF properties, and suggests new methods to supplement our early investigations in dynamically adaptive MRI (1, 8).

References