Highly Accelerated Projection Imaging (HAPI) with coil sensitivity encoding

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Target Audience: Scientists or researchers who are interested in rapid MRI and parallel imaging techniques

Introduction: Typical MRI protocols suffer from long data acquisition times. Parallel imaging techniques have been proposed to accelerate data acquisition. However, the acceleration comes at the expense of reduced and nonuniform distribution of signal-to-noise ratio (SNR). Recently, radial imaging has gained more attention for fast imaging since it is less prone to data undersampling than Cartesian encoding schemes. Some novel radial imaging techniques[1,2] formulated image reconstruction as an inverse problem, regularized the problem by constraints and solved it using a conjugate gradient method. These approaches produced good quality images demonstrating that radial encoding is capable of dealing with highly undersampled data. In the study presented here, we developed a new technique, named *Highly Accelerated Projection Imaging (HAPI) with coil sensitivity encoding,* which is capable of reconstructing a 2D image using fewer projections than the previous reports. The essence of this new technique is to densely sample each projection, which should be acquired at an angle other than 0 degrees or multiples of 45 degrees. The feasibility of this new technique was investigated with realistic simulations and experimental phantom studies. Simulation results show that 1-2 projections might be sufficient to reconstruct a 2D image. Experimental results demonstrated that HAPI is a promising new technique for fast imaging.

Methods: Inverse one-dimensional Fourier transform of an echo acquired at angle θ yields the projection of the object along the line determined by the same angle according to Fourier-slice theorem. Then, for the discrete case, a single matrix equation relating the object, **f**, and projections, **p**, can be formed as: **p = Af**. If the rays (isofrequency paths in each projection) are dense enough so that each voxel has several rays passing through it for a given projection, those adjacent rays span the voxel with different areas. So, each ray can be written as a weighted sum of all voxels that it passes through. Each voxel is further weighted by the sensitivities of the radio frequency (RF) coil array, providing additional information for solving the inverse problem. A sufficiently large number of such rays can be used to setup a system of linear equations, forming the **A** matrix (Fig. 1). If **A** is invertible, 2D image of the object can be reconstructed. Thus, the condition of **A** is critical. The effect of dense sampling on the condition of **A** is shown by eigenvalue distribution plots for different number of samples per projection, N_s (Fig. 2). It can be clearly seen that eigenvalues of **A** get closer to each other as the number of sampling points increases, improving the condition of the matrix substantially. However, it should be noted that the matrix condition will not improve for the critical angles, where adjacent rays cover the same amount of area in the voxel, for instance, 0 degrees or multiples of 45 degrees (verified by matrix condition plots; not shown here). For the solution of inverse problem, we used Sparse Equations and Least Squares method. We also implemented a regularization technique called total variation (TV) to reduce streaking artifacts, which is commonly used in undersampled radial imaging[1].

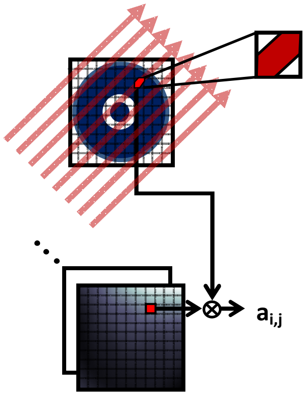

Fig 1. Formation of **A** matrix.

Simulations were performed using a modified Shepp-Logan phantom shown in Fig. 3. The amount of noise to be added to each projection was determined by calculating the projection SNR (pSNR) from the experimental data and found as 342 for this study. 1024 readout samples per projection were used in the simulations and 64×64 images were reconstructed using one and two projections. The experiments were performed using a 3T GE Signa Excite MRI system and an eight-channel phased-array head coil. Data were acquired from a cylindrical ACR MRI phantom using PROPELLER pulse sequence with "No-phase encode" mode turned on (TE= 90.6 ms, TR= 1000 ms, FOV= 22×22 cm^2, slice thickness= 5 mm, NEX= 2, number of projections= 43, sampling bandwidth= 62.5 kHz, samples per projection = 512). Three images (128×128) were reconstructed using 4, 8 and 16 projections.

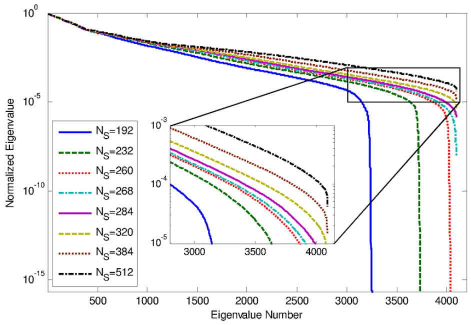

Fig 2. Normalized eigenvalue distribution for various N_s values (1 proj@20°, 64×64 image reconstruction)

Results and discussion: The top row of Fig. 3 illustrates the images reconstructed from the simulated phantom with the proposed HAPI technique using 1 and 2 projections. It demonstrates that 1-2 k-space lines might be sufficient to reconstruct a 2D image. Bottom row of Fig. 3 shows the results of the experimental study. The HAPI technique reconstructed images with negligible artifacts using 8 and 16 projections. Fine details with clear, sharp edges were preserved. The image obtained from 4 projections reconstructed the geometry of the phantom correctly and captured its details inside, but there were noticeable artifacts. It should be noted that we also tested the previously published projection techniques[3] but they did not converge at all when 4 projections were used. There might be various sources of error that led to these artifacts when only a few projections were used in experiments, thus we did not achieve the performance seen in simulations. First of all, simulations were performed assuming that complex RF coil sensitivity profiles can be measured precisely. Small errors in the estimation of RF coil sensitivities would propagate and result in reconstruction errors in experimental studies. When larger number of projections is used, the errors would probably average out and be less dominant. However, when k-space is highly undersampled, dependence on the accurate measurement of the physical environment increases and errors are magnified. Hence, the key for reconstructing superior quality images using only 1-3 projections would be to identify these systematic error sources and obtain accurate RF coil sensitivity profiles. Moreover, utilizing iterative techniques with constraints and filtering could reduce artifacts and improve SNR in future studies.

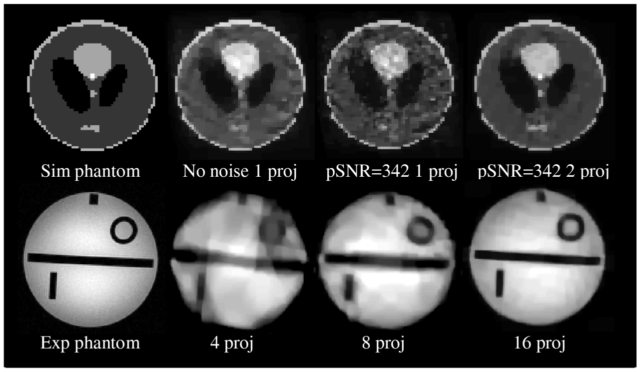

Fig 3. Reconstructed images for simulation and experimental studies.

References: [1] K.T. Block, *et al.* Magn Reson Med 57:1086-1098 (2007) [2] M. Uecker, *et al.* Magn Reson Med 63:1456-1462 (2010) [3] F. Knoll, *et al.* Magn Reson Med 67: 34-41 (2012).