Maximally Spaced Projection Sequencing for Uniform Acquisition of Electron Paramagnetic Resonance Imaging Projections

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Purpose: Electron paramagnetic resonance imaging (EPRI) is a robust magnetic resonance imaging modality providing 3D images of absolute pO_2 in vivo. When studying physiology in animals, the situation is inherently dynamic. Therefore, improvements in temporal resolution and the versatility to adjust temporal resolution to best fit the data and its application are crucially important. EPRI is often tomographic. Projections through an object are acquired in a 3D spherical geometry, which are then used to reconstruct an image using an inverse radon transform such as filtered back projection (FBP). The number and uniformity of the projections affect image quality. Uniform distribution of projections is preferable and has been extensively studied, e.g. [1,2]. When studying a dynamic system, in addition to ensuring uniformity in the final projection set, it is advantageous to acquire projections such that they are uniformly distributed throughout image acquisition. This provides advantages, such as the reduction of artifacts from changes during imaging, useful real-time reconstruction, and versatility to adjust temporal resolution by reconstructing intermediate images from subdivisions of the full projection set. One uniform acquisition method is based on the golden ratio and allows for acquisition maintaining approximate uniformity for any given number of projections and for any subset of those projections [3,4]. However, while this method is extremely versatile, it does not allow selection of an arbitrary, predefined final set of projections and never arrives at absolute uniformity. An alternative method is presented here, which starts from a final distribution of projections and acquires projections so that successive projections are maximally spaced from previously acquired projections. A comparison is made between these two methods, as well as a random projection selection method, demonstrating that the maximally spaced projection sequencing (MSPS) method provides comparable uniformity throughout image acquisition and therefore similar versatility to the golden ratio (GR) method while allowing one to arrive at any arbitrary final set of projections.

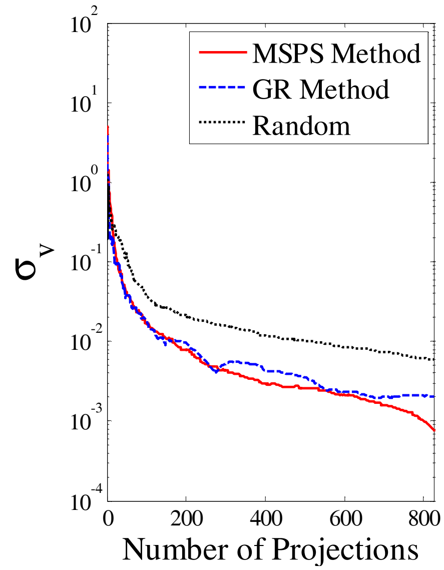

Figure 1: Comparison of the convergence to uniformity (σ_v to zero) as the full 828 projections are acquired.

Methods: Projection directions in 3D can be considered points on the surface of the unit sphere. Treating them as point charges, each successive point is chosen from the final set (in this case 828 points uniformly distributed using equal solid angle spacing) such that the electrostatic potential between itself and previously acquired points is minimal. At any given instance throughout acquisition, projection points will be maximally spaced from one another. The GR method used here for comparison has been detailed in the literature [3,4]. Random projection selection, where the Cartesian coordinates are randomized and mapped onto the unit sphere, is also used here for comparison.

For a set of points on the unit sphere, the portion of surface area occupied by each point can be found by calculating Voronoi areas. The standard deviation of these Voronoi areas (σ_v) will be used as a metric for the uniformity of a distribution of projection points (perfectly uniform points occupy equal areas yielding $\sigma_v = 0$) [1]. Simulated images of a digital phantom consisting of a large sphere with 5 smaller interior spheres of varying contrast using different acquisition schemes are compared. The image quality for images reconstructed from varying projection distributions is determined by calculating mean squared error (MSE) between the given image and an ideal image, reconstructed from a large number (14,330) of uniformly distributed projections satisfying the Nyquist requirement for the 64x64x64 image matrix.

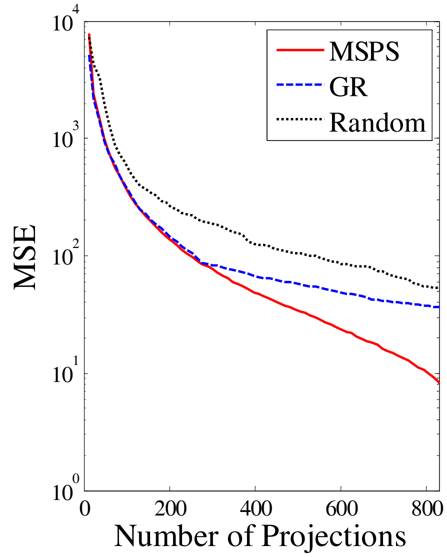

Figure 2: Comparison of image quality for intermediate images reconstructed as the full 828 projections are acquired.

Results: Figure 1 shows that using the MSPS method with a final set of uniformly distributed projections results in a comparable but more rapid convergence to uniformity and allows the acquired projections to arrive at a more uniform distribution than the GR or random methods. Figure 2 demonstrates the effect that this has on the fidelity of intermediate images reconstructed as projections are being acquired with the ideal image. It can be seen that for smaller projection numbers the MSE is similar for both the MSPS and GR methods, but as more projections are acquired the MSE for the MSPS method decreases more rapidly.

Discussion: Recently, the GR acquisition method has become widely used for projection based MRI because of its versatility to acquire arbitrary numbers of projections maintaining uniformity throughout acquisition and for subsets of arbitrary size. However, in certain circumstances it is useful to arrive at a desired final set of projections while maintaining uniformity during acquisition, which the GR method cannot do. One instance is when absolute uniformity is desired. Additionally, certain projections may contain more unique information for a given object than other projections (known *a priori* or determined from a scout scan). The MSPS method provides the versatility to acquire these projections, while maintaining approximate uniformity throughout acquisition.

Conclusion: A novel method for uniform acquisition of projections for EPRI is presented here. It provides similar uniformity throughout acquisition to the widely used golden ratio method but is a useful alternative in certain situations where the final projections are predetermined.

References:

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