Image Noise Considerations for PROPELLER k-space Sampling

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Introduction: PROPELLER imaging[1] is an MRI data acquisition and reconstruction technique that is rapidly attracting attention due to its greatly reduced sensitivity to motion and magnetic field inhomogeneities. Although, PROPELLER-MRI has been used for anatomical, diffusion, and perfusion imaging, the noise characteristics of the reconstructed images have not been investigated. The purpose of this work was to study the properties of noise in PROPELLER-MRI, which will facilitate the design of optimal acquisition and reconstruction strategies.

Methods: Simulations of PROPELLER data acquisitions were performed. The simulated object was the Shepp-Logan phantom[2]. Since its k-space image is known analytically, the exact value of any sample in k-space can be determined accurately. In all PROPELLER acquisitions, each k-space line included 128 samples, and all samples were gridded onto a 128x128 Cartesian grid. Gaussian noise was simulated in k-space (for both the real and the imaginary part). Each blade sampled a different realization of the noisy k-space phantom data. In order to estimate statistical quantities such as standard deviation, an ensemble of noisy k-space realizations were simulated (100-500). Initially, a PROPELLER grid with 12 blades and 16 lines was used. The standard deviation in different parts of k-space was studied after gridding. Estimation of standard deviation in image space was performed on a pixel-by-pixel basis, and the results from a 10x10 region inside the phantom were averaged. Well-defined 11x11 regions of k-space that corresponded to increasing spatial frequencies were reconstructed separately, and the standard deviation in the reconstructed images as a function of the spatial frequency content of the sampled information was determined. The same process was followed for a conventional acquisition, where samples were obtained directly on the 128x128 Cartesian grid. Noisy images were also reconstructed using all of the k-space that was sampled (instead of small 11x11 parts of it), for both PROPELLER and Cartesian sampling. Next, the covariance was measured in image space for both PROPELLER and Cartesian sampling. To measure the covariance, a point (x_0, y_0) was selected in the Shepp-Logan phantom, and only points (x, y_0) were considered. All results were compared between the two acquisition patterns.

Low-quality blades can be identified in PROPELLER by comparing the central region of k-space sampled by each blade with the mean central region of k-space estimated using all blades. Then, low-quality samples are weighted less than high-quality samples during the reconstruction process[1]. Thus, the next step of this work was to investigate the effects of “quality” weighting on the noise of the reconstructed images. For this purpose, three adjacent blades were given a set of weights: 1 (high quality data), 0.8, 0.6, 0.4, 0.2, 0 (very low quality data), while each other blade was given a weight of 1. The standard deviation and covariance in the reconstructed images were estimated for the different “quality” weights.

Finally, the standard deviation in the PROPELLER images was measured for sampling patterns that included different numbers of lines per blade, as well as different numbers of blades. The samples from all patterns covered the same circular region of k-space.

Results and Discussion: Figure 1 shows that the standard deviation of gridded PROPELLER k-space data increases with spatial frequency, due to the increased sampling density of the PROPELLER acquisition pattern near the center of k-space. For that reason, in PROPELLER sampling, when reconstructing images from regions of k-space that correspond to different spatial frequencies, the standard deviation of the image-space signals increases with spatial frequency (Fig.2). For Cartesian sampling, the standard deviation in image-space is independent of spatial frequency since noise is uniform across k-space (Fig.2). No significant difference was found in the image covariance reconstructed from PROPELLER and Cartesian sampling. In regards to the “quality” weighting, the standard deviation in image space was increased as 3 of the blades were weighted less than the rest (Fig.3). However, when assigning a weight of 0 to these 3 blades, the standard deviation was significantly reduced. This was due to the fact that rejection of 3 blades created a gap in high spatial frequencies, which resulted in smoothing and reduced standard deviation. Also, the FWHM of the central peak of the covariance in the reconstructed PROPELLER images did not significantly change for weights between 0.2 and 1, but was approximately 2.5 times higher for a weight of 0. This was due to the fact that when the weight is not 0, data are still present in the high spatial frequencies sampled by the 3 blades, and no smoothing occurs (only an increase in noise). When the weight becomes 0, then smoothing causes the FWHM of the central peak of the covariance function to increase. Finally, the standard deviation in image space decreased with increased number of lines and blades, as expected (Fig.4). Also, when comparing a PROPELLER acquisition scheme with 24 blades, uniformly distributed in k-space, and a scheme with 12 blades acquired twice, (same number of lines/blade and samples/line), there was no significant difference in the standard deviation of the reconstructed images.

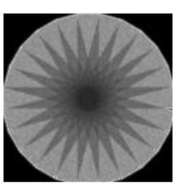

Figure 1. Map of the standard deviation of gridded PROPELLER k-space data.

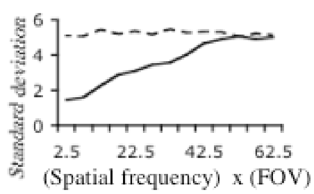

Figure 2. Graph of the mean standard deviation for images reconstructed from different regions of k-space. The continuous and dotted lines correspond to PROPELLER and Cartesian sampling respectively.

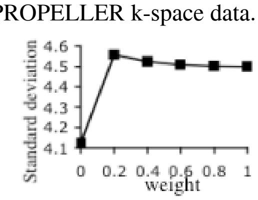

Figure 3. Mean standard deviation in image space as a function of the weights applied on 3 adjacent blades.

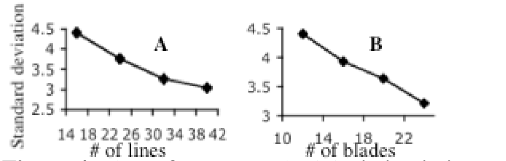

Figure 4. Plots of mean standard deviation in image space as a function of the # of lines (A), and the # of blades (B) of the PROPELLER sampling pattern.

This work compared the properties of noise in PROPELLER to those in Cartesian sampling. Also, the noise characteristics of PROPELLER were studied as a function of different acquisition and reconstruction parameters. We expect that these findings will facilitate the development of optimal PROPELLER acquisition and reconstruction strategies.

References: 1) Pipe JG, et al., MRM 47:42 (2002). 2) Shepp LA, et al, IEEE Trans Nucl Sci NS-21:21 (1974).