Reduced Ring Artifacts for PROPELLER Using An Analytical Density Compensation Algorithm During Regridding into Cartesian k-space

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Introduction

PROPELLER collects rectangular blades rotated about the k-space origin by using the fast spin echo (FSE) acquisition scheme. Since more blades are overlapped in the center of k-space, the low frequencies are sampled more densely than the high frequencies. The fast Fourier transform (FFT), an efficient signal processing technique requiring uniform sampled data, cannot be applied to such non-uniformly sampled k-space directly. In order to use the FFT, a gridding method has been used to transform the non-uniform data to regularly Cartesian-gridding data. To compensate non-uniform sampling before gridding, an iterative numerical solution [1] for PROPELLER sampling density estimation was implemented by Pipe, which requires convolution of an optimized kernel with the sampling pattern. However, because there is no deconvolution step (such as a roll-off filter in image space) available for kernel convolution involved in this iterative solution, which is exclusively in k-space. This may lead to modulation artifacts being introduced into reconstructed images. To reduce these artifacts, we propose an analytical solution for density correction based on the PROPELLER sampling pattern to avoid kernel convolution.

Method

Each blade of PROPELLER is uniformly sampled with rotation angle θ_i and correlation weight c_i. To obtain uniformity across k-space, the weights in non-overlapping region are set to 1.0, while a weight of blade *i* at (k_1, k_2) in an overlapping region is calculated as (1). The weights can also be calculated one blade at a time. The weighs of each blade are initialized as 1.0. For each blade *i*, every other blade *j* is rotated relatively in angle $\theta_j - \theta_i$ and each weight of blade *i* in its overlapping region with blade *j* is updated as (2) (as illustrated in Figure 1). The density compensation weights of blade *i* are obtained after considering contributions from rest of the blades. Comparison tests were done on a 1.5T GE Signa scanner, using three bottles (TR/TE=2500/98.6, ELT=20, matrix size=256×256, slice thickness=5mm) and ACR phantom in a head coil (TR/TE = 1000ms/110ms, ETL=28, matrix size=256×256, slice thickness=5mm).

$$w_i(k_1,k_2) = \frac{c_i}{\sum_{\text{all overlapping blades}} c_m} \quad (1)$$

$$w_i^{(n+1)}(k_1,k_2) = \frac{w_i^{(n)}(k_1,k_2)}{1 + w_i^{(n)}(k_1,k_2) \times c_j / c_i} \quad (2)$$

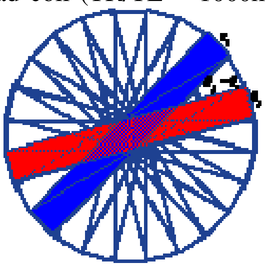

Figure 1. An illustration of PROPELLER sampling pattern

Results

Figure 2 shows the reconstructed images of the raw data from three bottles; Figure 3 shows the reconstructed images of the raw data from an ACR phantom using iterative solution (left) and proposed analytical solution (right). The ring artifacts (pointed by red arrows) introduced by previous weights density compensation near the image center smear the bright spots in the center circle, while the new proposed analytical solution gives more uniform background and shows the spots clearly.

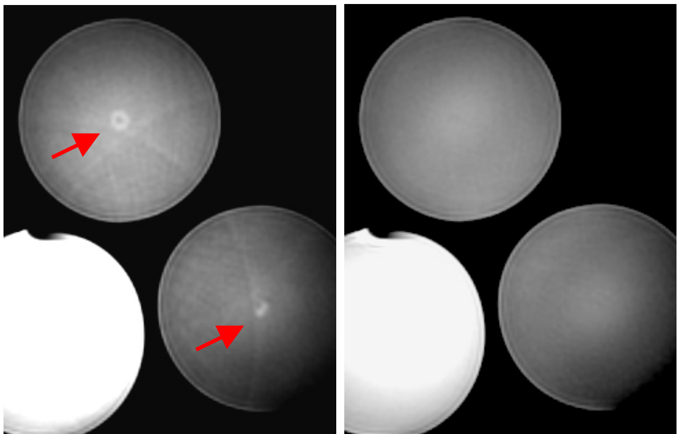

Figure 2. The reconstructed images using iterative density compensation (left) vs. the image with the analytical solution (right)

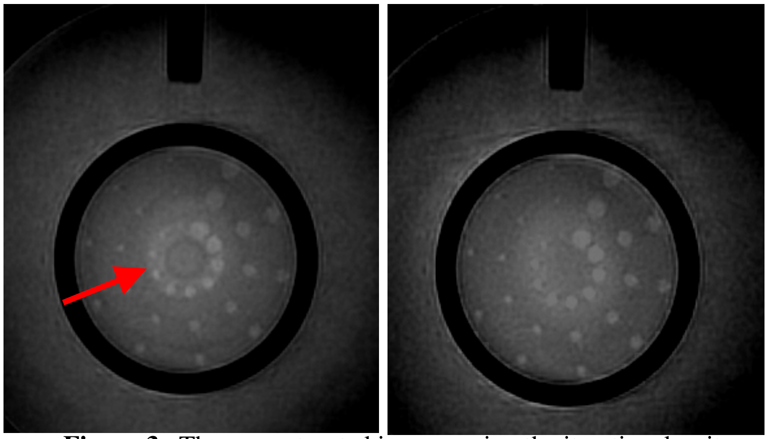

Figure 3. The reconstructed images using the iterative density compensation (left) vs. the image with the analytical solution (right)

Conclusions: We recommend an analytical density compensation method for PROPELLER, which requires no convolution in k-space and reduces ring artifacts in phantom tests. In addition, this method is computational efficient as does not involve iterative refinement as the other algorithm [1].

Reference: [1] James G. Pipe, Magnetic Resonance in Medicine 42:963—969, 1999