An Inexpensive Iterative Reconstruction for Under-sampled PROPELLER MRI

Jyh-Miin Lin[1,2], Tzu-Chao Chuang[2], Hing-Chiu Chang[3,4], Wen-Chau Wu[5], and Hsiao-Wen Chung[4,6]

[1]*Department of Radiology, Duke University Medical Center, Durham, NC, United States,* [2]*Department of Electrical Engineering, National Sun Yat-sen University, Kaohsiung, Taiwan,* [3]*Global Applied Science Laboratory, GE Healthcare, Taipei, Taiwan,* [4]*Institute of Biomedical Electronics and Bioinformatics, National Taiwan University, Taipei, Taiwan,* [5]*Graduate Institute of Oncology, National Taiwan University, Taipei, Taiwan,* [6]*Department of Electrical Engineering, National Taiwan University, Taipei, Taiwan*

Introduction

Periodically Rotated Overlapping ParallEL Lines with Enhanced Reconstruction (PROPELLER) is an MR technique less susceptible to motion at the cost of longer acquisition. To sustain the acquisition time as that of Cartesian scans, k-space undersampling is an approach(1) accompanying higher computational expense than FFT. Although it has the ability to reach superior image quality(2), iterative optimizations tend to requires more memory and computation than conventional Cartesian scans.

In this study we implement an inexpensive reconstruction named Image Space Reconstruction Algorithm (ISRA), which is originally used to reconstruct nuclear imaging with less streaks(3). As a deblurring algorithm, specifically, ISRA compares the estimated image in the image space, rather than in k-space, thus causing faster convergence than maximal likelihood method but slightly worse final root-mean-square errors. In particular, ISRA may be useful for clinical PROPELLER images for two reasons. First, instead of conventional iterative reconstruction using raw data, the estimated image and the "raw-image" ($\boldsymbol{x_{blurred}}$) are compared in the image space where memory can be largely saved. Second, because the PROPELLER encoding is an image modulation in k-space, the forward transformation is quickly done through fast Fourier transform(FFT). Phantom experiments were performed to examine the feasibility of the proposed method.

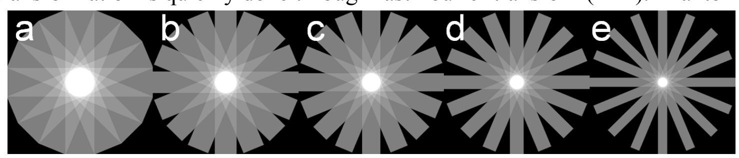

Fig.1 The full-coverage k-space (a) and under-sampling (b-e) patterns of PROPELLER sampling scheme. Each consists of 8 blades. From a to e, the narrower blade leads to less k-space coverage, or larger gaps between blades.

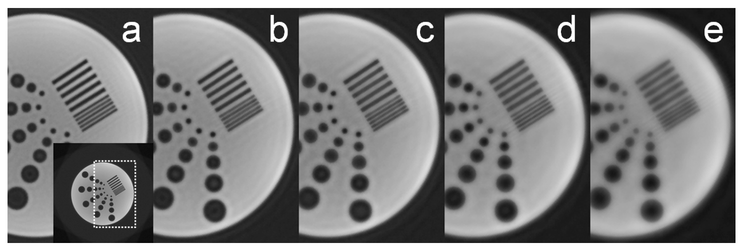

Fig.2 Enlarged and cropped views of raw images ($\boldsymbol{x_{blurred}}$) of the sampling schemes in Fig.1. The original image is shown in the corner of a.

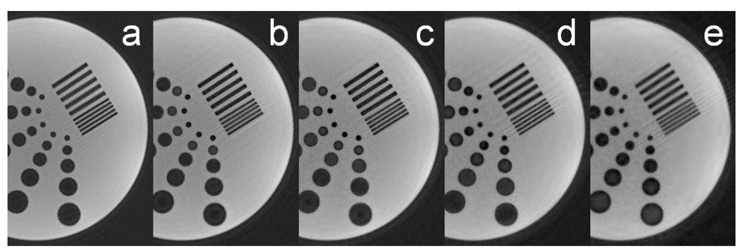

Fig.3 PROPELLER images corrected by ISRA algorithm.

Theory and Method

Generalized inverse (4) reaches the pseudo-inverse of an arbitrary complex matrix $\boldsymbol{A}$ by the following iteration:

$$A^{-1}{}_{i+1} = A^{-1}{}_i (2I - AA^{-1}{}_i),\ i=0,\ 1,\ 2,\ \ldots$$

where $\boldsymbol{A^{-1}{}_i}$ is the generalized inverse. Given the above-mentioned iteration, we reach the limit of reconstructed image by inserting the data $\boldsymbol{y}$ into the generalized inverse, yielding image reconstruction:

$$A^{-1}{}_{i+1} y = A^{-1}{}_i y + (A^+ - (A^+ - A^{-1}{}_i))y - (A^+ - (A^+ - A^{-1}{}_i))AA^{-1}{}_i y$$

$$x_{i+1} = A^{-1}{}_i y + (A^+ y - A^+ AA^{-1}{}_i y) - (A^+ - A^{-1}{}_i)(I - AA^{-1}{}_i)y$$

$$\approx x_i + (x_{blurred} - A^+ Ax_i)$$

which is the image space reconstruction algorithm (ISRA):

$$x_{i+1} = x_i + (x_{blurred} - A^+ Ax_i)$$

in which the initial reconstructed image with blurred borders are denoted as $\boldsymbol{x_{blurred}}$ and $\boldsymbol{x_i}$ is the estimated images in each step. $\boldsymbol{A}$ is the signal acquisition transformation determined by k-space sampling pattern and subject movements.

Data Acquisition and Processing:

PROPELLER sequence with fast gradient echoes was modified from the fast SPGR sequence on a clinical 1.5 T scanner (Signa HDx, GE Healthcare, Milwaukee, WI). A home-made phantom containing various size of cylindrical bars and rectangular plastic plates was scanned with these parameters: TE=5.9 ms, TR=12.3 ms, slice thickness=4 mm, flip angle=20 degree, and 512 readout encoding steps. We performed experiments to create PROPELLER images as was shown in Fig. 1. To evaluate the influences of under-sampling, five sets of eight blades with different phase encoding steps (102, 76, 64, 48, and 32) were acquired.

Results and Discussion

Figure 2 shows noticeable degradation of image quality from a to e. Notice that the "raw images" were obtained only through rotation and superposition of blades, without sampling density compensation in k-space. From a to e, the total numbers of k-lines were 816 to 256, diminishing the sampling time from 160% to 50% of Cartesian sampling. In Fig. 3, the proposed ISRA reconstruction largely improved the quality of c to e. Regardless of this visually superior quality, the images of d and e nevertheless have mild residual artifacts around structures with high-spatial frequencies. Even with these mild imperfections, the details of these fine structures were clearly identifiable. In conclusion, this study depicts the merits of ISRA to reconstruct under-sampled PROPELLER images, although further clinical investigation is required. In our study, the iteration achieves convergence within 2~3 seconds on a modern personal computer (using a 1.6GHz dual core CPU) for images with 512 readout encoding steps. The reconstruction $\boldsymbol{A^+}$ is as simple as the rotation and superposition of blade images at each angle. ISRA method may be further integrated into advanced hardware and software to improve its efficiency.

Acknowledgement

We acknowledge the support of National Science Council (NSC 99-2221-E-110-010, NSC 97-2314-B-002-172-MY3). We thank the facility and technical support of Kaohsiung Veteran General Hospital (Kaohsiung, Taiwan).

References

1. Arfanakis K, MRM 2005;53(3):675-683.
2. Tamhane AA, JMRI 2010;32(1):211-217.
3. Titterington DM. Medical Imaging, IEEE Transactions on 1987;6(1):52-56.
4. Ben-Israel A. Mathematics of Computation 1965;19(91):452-455.