A MAGNITUDE-BASED ASYMMETRIC FOURIER IMAGING (MAGAFI)

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Purpose:

Asymmetric Fourier Imaging (AFI), which is a MR image reconstruction technique using the asymmetrically sampled data around the center of k-space based on Hermitian conjugate theory, is widely used to reduce imaging time and shorten TE while minimizing blur. Several AFI techniques have proposed and applied [1-5]. The simplest algorithm is Margossian [1] or Homodyne [2] technique where the phase estimation is performed from the symmetric low frequency portions in k-space. However they sometimes induced artifacts due to imperfect phase estimation when applying to gradient echo (GRE) imaging. Recent techniques of POCS (Projection on to Convex Sets) [3] or Cuppen [4], where the iteration is performed under the constraint of assumption that only real component contains in the image after phase correction, can reduce such artifacts induced by non-iterative methods at the cost of computing time. Meanwhile, a method of substituting zeros for unmeasured k-space data (0-filling) is also widely used despite of blur due to its simplicity and small phase-induced artifacts. The purpose of this study was to propose and assess a new AFI technique named MagAFI where the phase information is not required but only the magnitude image with 0-filling is used; and in addition, MagAFI combining with POCS was also proposed and assessed.

Methods:

Basic idea of MagAFI is based on the following two knowledges. First, the phase in real-space (r-space) reconstructed from the whole k-space sampled data including high-frequency asymmetric portion is close to the fully-sampled data compared to that made from only the low-frequency k-space symmetric region as shown in **Fig. 1-c, d**. Second, the r-space data after phase correction using the whole sampled data is equivalent to the magnitude of r-space data with 0-filling method. Although the similar idea has shown by McGibney as a technique named MoFIR [1], his technique requires whole phase information and the effects on actual MR data was not so clear. Here we consider a 1D case to simplify and define as follows: k-space data is S(k), real-space (r-space) data is V(r), and AFI image data is $I_{cor}(r)$; original partially sampled k-space data: $S_{orig}(k)$: $-K_c<=k<=K_{max}$ ($K_c<K_{max}$), where zeros are filled in unsampled region ($-K_{max}<=k<K_c$);

low-pass filter: $H_{low}(k) = 1$: $|k|<= K_c-K_1$, $=\exp[(-\ln 2)\{(k-(K_c-K_1))/K_2\}^2]$: $K_c-K_1< |k|<=K_c$, $=0$: otherwise;

homodyne high-pass filter : $H_{high.homo}(k) = H_{low}(k)$: $k<0$, $=2- H_{low}(k)$: $k>=0$;

filter to reduce truncation artifacts for whole data: $H_{whole}(k)=H_{low}(k)$: $-K_{max}<=k<0$, $=1$: otherwise;

filter to enhance high-frequency of $|k|> K_c$ for MagAFI: $H_{high.sym}(k) = 2/\{1+ H_{low}(k)\}$;

In this AFI algorithm, each filtering is performed in k-space and the phase correction is performed in r-space, the range for Fourier transform (FT) and inverse Fourier transform (IFT) are $-K_{max}<= k<= K_{max}$. Conj[] means taking conjugation. Each AFI algorithm assessed here is as follows:

Margossian (Homodyne)

1) Low-pass filtering: $V_{low}(r)=FT[H_{low}(k) * S_{orig}(k)]$.
2) Homodyne filtering: $V_{high.homo}(r)= FT[H_{high.homo}(k) * S_{orig}(k)]$.
3) Phase correction: $V_{cor}[r]= V_{high.homo}[r]*Conj[V_{low}(r)]/|V_{low}(r)|$.
4) Take real-part in r-space: $I_{cor}(r)=Real[V_{cor}(r)]$.

MagAFI

1) Windowing whole data: $S_{whole}(k)=FT[H_{whole}(k)*S_{orig}(k)]$.
2) Generate magnitude image: $I_{whole}(r)=|FT[S_{whole}(k)]|$.
3) High-pass filtering: $S_{cor}(k)=H_{high.sym}(k)*IFT[I_{whole}(r)]$.
4) Take real-part in r-space: $I_{cor}(r)=Real[FT[S_{cor}(k)]]$.

The $IFT[I_{whole}(r)]$ becomes perfectly Hermitian conjugate in k-space because the $I_{whole}(r)$ has only real-part components, while the gain of the unsampled region is about a half of fully-sampled data. The aim of filter $H_{high.sym}(k)$ is to compensate the reduced gain. When there is magnitude image with 0-filling, the step 1)~2) are skipped.

POCS combination

The data $I_{cor}(r)$ obtained by MagAFI or Margossian are defined to be the initial (n=0) data of POCS as $I_{cor}(r,0)=I_{cor}(r)$. The next step of 5) to 8) is iterated for N times (n=1~N) until convergence.

5) Phase restoration: $S_{cor}(k,n)=IFT[I_{cor}(r,n-1)* V_{low}(r)/|V_{low}(r)|]$.
6) $S_{merge}(k,n)=\{1-H_{whole}(k)\}*S_{cor}(k,n)+H_{whole}(k)* S_{orig}(k)$.
7) phase-correction:
   If Margossian: $V_{cor}(r,n)= FT[S_{merge}(k,n)]*Conj[V_{low}(r)]/|V_{low}(r)|$.
   If MagAFI : $V_{cor}(r,n)= FT[S_{merge}(k,n)]*Conj[V_{whole}(r)]/|V_{whole}(r)|$.
8) Take real-part in r-space : $I_{cor}(r,n)=Real[V_{cor}(r,n)]$.

Experiments

Experiments were performed using normal volunteer brain MRI data of heavy T2*W named FSBB [6] acquired on 3T Toshiba Vantage Titan™ (Otawara, Japan) after obtaining written informed consent: 3D-GRE, TR/TE/FA=29ms/20ms/15deg., b-value=4s/mm^2, slice thickness=2mm, acquisition matrix=256x256 (fully sampled), and parallel imaging of reduction-factor-factor, R=2. For AFI parameters, K_c=16, truncated the front of read-out direction (anterior to posterior), K_1=8, and $K_2=K_1/2$ were used. Four AFI algorithms of Margossian, MagAFI and each combination with POCS were compared visually and quantitatively using Root Mean Square Error (RMSE) of whole pixels between fully-sampled image normalized by mean of fully-sampled image.

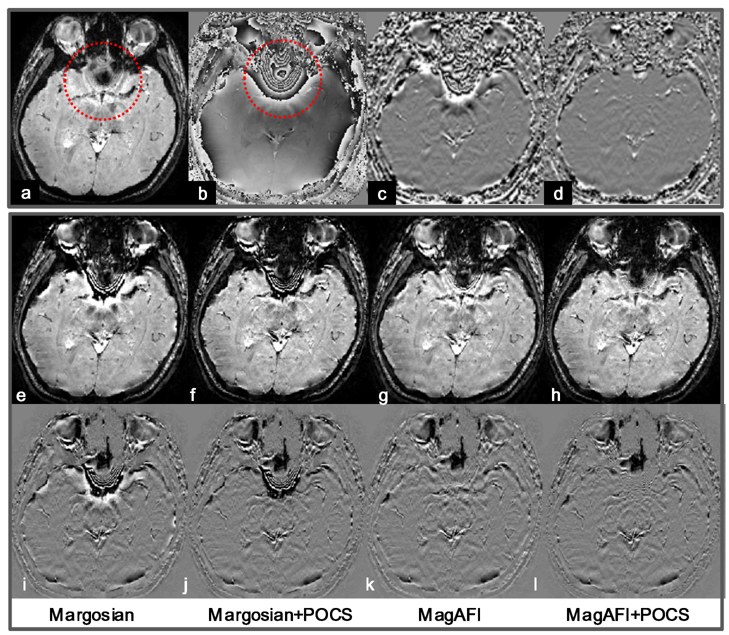

Fig. 1 Results for 3T FSBB (3DGRE TE=20ms) data. The 1st row is fully sampled (-128~128) images of magnitude (**a**), phase (**b**), and residual phase after phase correction using H_{low} (**c**) and H_{whole} (**d**). The 2nd row (**e-h**) is AFI images using partial data of K_c=16 (-16~128) with denoted AFI algorithm and the 3rd low (**i-l**) is subtracted image between fully sampled and each AFI image. Portions near the nasal sinus of greater phase changes (red circle) demonstrated large residual phase in (**c**) than (**d**); and correspondingly introduced smaller errors in the MagAFI's (**k, l**) than in the Margosian's (**i, j**) for both stand-alone and each POCS combination. Those RMSEs[%] were reduced from left to right as 42.3, 39.1, 30.4, and 29.3, respectively.

Results and Discussion:

Image blurs on the image with 0-filling (not shown) was improved by MagAFI. As shown in **Fig. 1**, the MagAFI introduced smaller artifacts than the Margossian did in the portion of large and spatially high-frequency phase, reflecting the difference of residual phase error after phase correction; in contrast, those two methods provided almost comparable results in the portion of spatially low-frequency phase. The each combination with POCS further reduced the RMSE. However, the POCS with Margosian was never close to the POCS with MagAFI even if increased the number of iterations, N.

Conclusion:

Our proposed MagAFI is practically useful algorithm from the views of balancing image quality and simplicity, since it can be achieved using only 0-filling magnitude image. If allowing us to use phase information and to spend an additional time, MagAFI combining POCS is further better to improve image quality and robustness.

References:

[1]Margosian et al. Health Care Instrum.1,195(1986); [2] Nolls et al. IEEE Trans. Med. Imag. MI-10(2),154(1991); [3] Haacke, JMR, 92,126(1991); [4] Cuppen at.al. MRI,5,516(1987); [5] Macgibney et al. MRM 39:51-59(1993); [6] Kimura et al. MRM,62:450-458(2009).