Fast Imaging of Dynamic Objects Using POCS Based Partial Fourier Reconstruction Along Time

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INTRODUCTION:

Many approaches to fast MR imaging seek to reduce k-space acquisitions and exploit data redundancies during reconstruction. Partial Fourier reconstruction (PFR) techniques [1] exploit phase reconstruction and conjugate symmetry to estimate the missing k-space data values. Although this conventional approach applies to individual images within a dynamic sequence, further exploitation of this basic idea across the temporal aspect of a dynamic sequence is not straightforward. We note that the phase that is present in complex MR images may be either due to the artifacts like nonuniform receiver coil sensitivity, susceptibility, B0 inhomogeneity, or it may be due to motion or velocity etc. [2] that is deliberately encoded by the pulse sequence and therefore changes as the object moves. In either case, the static portion of MR images of dynamic objects (such as the heart) should have unchanging phase over the image sequence, and this remaining redundancy can be exploited for further decrease in imaging time. In this work, we propose a method to estimate the phase of the static portion of the phase to reconstruct an MR image at particular time instant from the data samples acquired at that time instant.

METHODS:

Phase Estimation: Conventional PFR estimates phase over the whole image from the subsampled data acquired at a given time instant. In our technique the phase is estimated from an average image, averaged in the temporal direction. The average image is computed from the k-space data, where each k-space location is an average value of that particular k-space location over the whole time sequence. Note that the k-space data can be acquired in any sampling pattern as long as all the k-space locations are sampled at least once during the whole time series. Since the addition and/or subtraction of complex numbers with the same phase is also a complex number with the same phase, the phase of the static portion in the average image corresponds to the phase of the static portion of image at all time instants.

Image Reconstruction: We assume the phase to be known over the static portion of the image sequence; this provides some data at each time instant. In addition, there are assumed to be some k-space observations at each time instant. Projection onto convex sets (POCS) [3] can be used to account for both types of information in the image reconstruction operation. POCS reconstruction is given by the iterative application of two operators, as follows:

Data consistency operator:

$$I^{n+1}(x) = P_{DS}\{ I^n(x)\} = \text{IFFT}\{ \text{FFT}\{ I^n(x)\}(k) * (1 - D(k,t)) + F(t,k) * D(k,t) \} \quad (1)$$

Phase consistency operator:

$$I^{n+1}(x) = P_{PS}\{I^n(x)\} = I^n(x) (1 - S(x)) + |I^n(x)| * \exp\{j \text{ angle}(I_{av}(x)\} * S(x) \quad (2)$$

Hence, one step comprising both operators and yielding an updated image is given by

$$I^{n+1}(x) = P_{DS}\{ P_{PS}\{I^n(x)\} \} \quad (3)$$

In Eqn (1), the data sampling indicator function is $D(k,t) = 1$ if k-space location k is acquired at time instant t; otherwise, it is zero. In Eqn (2), the static portion indicator function is $S(x) = 1$ if the spatial location x belongs to static portion; otherwise, it is zero.

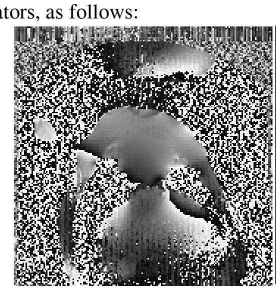

Fig 1: Estimated phase for 75% data.

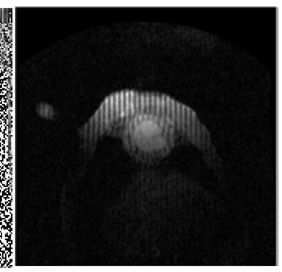

Fig 2: Ground truth.

RESULTS AND DISCUSSION

We evaluated our technique by reconstructing a 1-1 SPAMM tagged MR image sequence. The magnitude of a tagged MR image sequence changes with time due to tag fading while the phase of the static portion remains the same over time. Data from a tagged MR image sequence of an infarcted pig was used. Parameters were 176x176 Cartesian sampling grid; FOV =300 mm, slice thickness = 8mm; and tag spacing = 6 mm. The direction of the phase-encode and frequency encode directions were reversed between horizontal and vertical tagged images for better motion artifact suppression. Data reduction was applied (artificially, after acquisition of the whole data) in the phase encoding direction – e.g., 75% data corresponds to images reconstructed using only 75% of the phase-encode lines. Sampling of the phase encodes was done in bit-reversed order [4] to generate sub-sampled data. The central half of the image was assumed to be dynamic.

The proposed technique was applied when 100, 93.5, 87.5, 81.25, 75, 68.75 and 62.5 percent of the data is known at each time instant. Fig 1 shows the estimated phase obtained from the average image when reconstructing from 75% of the data. Fig 2 shows a snapshot of the true vertical tagged MR image at one time instant. The two columns in Fig 3 correspond to the reconstructed MR image (left) and the magnified (10X) error in the reconstructed MR image sequence, where each image is zoomed over the central half of the reconstructed image. The three rows in Fig 3 correspond to reconstructions done when 87.5, 75, and 62.5 percent of the data is acquired. Fig 4 shows the percentage of total energy present in an image in the error against the percentage of data acquired at one time instant.

Fig 3 suggests that the error in the reconstructed images is white and uniformly spread over the whole area. This is due to the conventional decrease in SNR phenomenon when fewer amounts of data are used to reconstruct an image. We have assumed only 50% of data is static so we can apply this technique when more than 75% of data is acquired at one time instant. But there is only 0.21% energy contained in the error even though when 62.5 % of data is acquired.

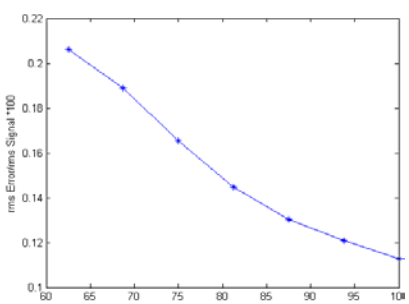

Fig 4: Percent of total energy of an image present in the error (rms error / rms signal *100) vs Percent of data acquired at one

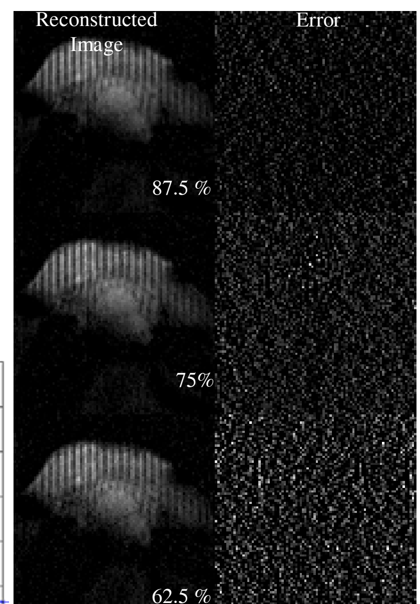

Fig 3: Reconstructed image and (10X) magnified error for images reconstructed from different amount of data acquired at one time instant.

CONCLUSION

We have presented a fast MR imaging technique that uses the redundancy present in the phase of the static part of an MR image. We have provided the novel technique for phase estimation and a POCS approach to reconstruction. We used the example of tagged MR image to show that this technique can be applied to an MR image sequence of a dynamic object.

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